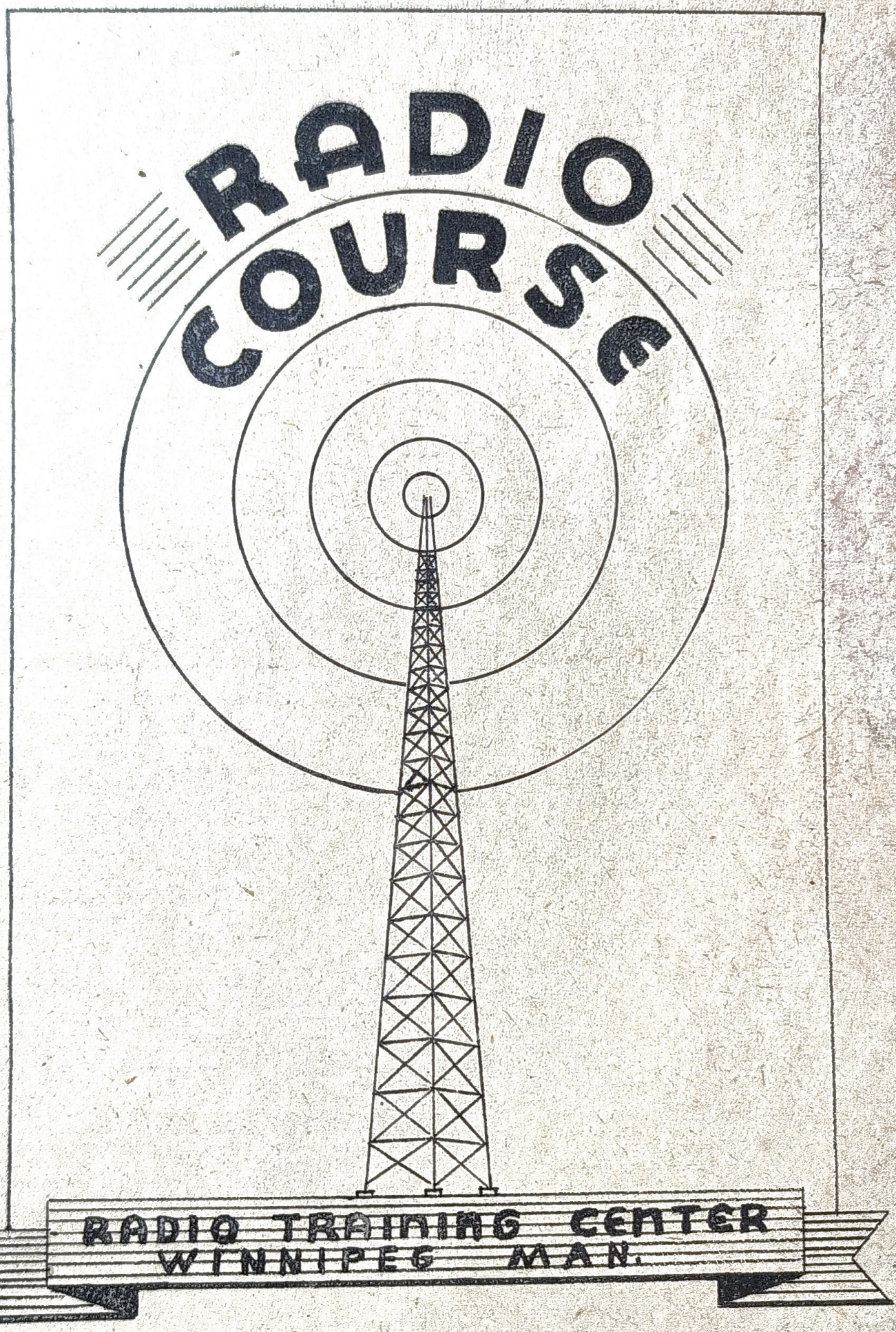
RADIO
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LESSON ONE

INTRODUCTION

THE ELECTRICAL AGE

Science is marching on at an ever increasing speed. The electronic era has been definitely ushered in and we are living today in an electrical age--an age full of twentieth century wonders, and, to the uninitiated, an age of magic. Not the Black Magic of Practitioners of Sorcery and witchcraft of olden times, but a new scientific type that can be very appropriately designated as "Electronic Magic".

This magic is performed by infinitely small particles of negative electricity called electrons. These particles, rushing rapidly back and forth through highways of slender copper, produce and place at the disposal of Man many of the luxuries and refinements of modern living which were not available a century ago, but which are enjoyed extensively by the masses of today. All this is made possible by improving, and perfecting to a high degree, the technical art of applied electricity.

Contemplate for a moment the dire disaster which would befall the world if all electrical activity were to cease entirely. It is obvious that the high standards of present day living could no longer be maintained. Civilization would rapidly deteriorate. Conditions of life would drop to the same low evolutionary level occupied by men many hundreds of years ago.

Let us briefly review some of the most notable discoveries of recent years so that we may see what wonderful strides have been made in scientific development within the past decade. When we view the marvelous advancements of the past few years, we naturally turn in wonder to the future. What will it bring forth in the way of new discoveries? What amazing peaks of scientific development will it unfold? Will the future reveal tremendously higher standards of life for all? We cannot say for certain, but if science continues to push on at ever increasing speed, as it is now doing, then such a future would seem to be inevitable.

ARTIFICIAL SUN

Scientists and engineers have discovered within recent years that Ultra Violet light can be artificially produced. Proper apparatus and devices have been perfected to produce Ultra Violet Radiations in the home, and thousands suffering from a deficiency of Vitamin D have received substantial health benefits as a result of this new development.

Although the cost of producing these artificial health giving rays is somewhat too high at present, engineers are working on new "Health Ray Bulbs" which, when perfected, will enable every household to equip each room with an artificial sun at a cost of only a few cents per bulb and requiring no extra equipment. Thus with the aid of electricity it may yet be possible to "bring the sun indoors".

COSMIC RAYS--DEATH RAYS

So-called "death rays" have already been discovered by electronic

engineers. These rays are short and powerful radio waves which have been found to possess very deadly and detrimental properties in that they cause death to animals which have been exposed to the radiation. But, since these radiations are only effective at very close range, it is doubtful whether they will ever be used as a weapon of destruction in times of war.

Much more interesting from the standpoint of effective usefulness, are the new mysterious "Q Rays". These rays, it is claimed possess the peculiar property of deranging the ignition systems in gasoline type motors. If all that is claimed for these radiations is true, their use will enable a single operator to render ineffective whole air squadrons and much other motorized war equipment.

Cosmic Rays have also aroused keen interest among scientists. High mountains have been scaled and may stratosphere flights made in order that these unknown and mysterious rays might be studied. These rays have the unusual property of being able to penetrate a great thickness of lead--something that no other radiation is capable of doing. What vital part do these radiations which come to us from the boundless space of the outer universe, play in our lives? As yet we cannot say, for we know very little about them. But the next few years may see the answer to this question revealed.

TRANSMUTATION A COMING POSSIBILITY

In centuries gone by scientists attempted to discover the secret of transmutation--the ability to change one element into another. Many attempts were made to change lead into gold, but these were not successful. It is true that various formulas were evolved which enable these chemists to produce useful metallic aloys, but at no time did they discover the secret of how to bring about a change in the atomic structure of the metals employed. Yet such a change is necessary if one element is to be converted into another.

Now science is again attacking the problem of transmutation, this time with the aid of electricity. The realization of this age old dream of alchemists is sought not through chemical means, as in ages past, but is to be the result of carefully planned electronic research. The possibility of converting lead into gold has already been demonstrated as feasible, and this, the most seemingly impossible of all feats, has been accomplished to some degree in modern scientic laboratories.

By constructing large vacuum tubes and by generating extremely high electrical voltages, a stream of electrons may be directed to strike a given piece of metal at tremendous velocity. By the force of this electric impact, a displacement of the electrons and protons may be affected. This change in atomic structure of metals has already been successfully accomplished on a small scale, and thus, for the first time in the history of science, one element has been converted into another. True, there are many practical difficulties to be overcome before this process may be successfully commercialized; but one day these difficulties will be eliminated, and when that day comes, this discovery will be the greatest and most spectacular in the history of the world.

In the near future we may well expect to see gigantic factories equipped with transmutation apparatus consisting of long porcelain vacuum tubes and

powerful voltage generators specially designed for the "Transmutation Process". When these transmutation facilities have been perfected, it will be possible to create new elements as and when desired. Lead will be changed into gold, iron into copper, hydrogen gas into helium, and ordinary salt into the precious radium. All this must sound very fantastic and almost too good to be true, yet this is a scientific probability and much closer to realization now than ever before.

ATOMIC ENERGY

Modern Scientists have discovered that there is tremendous power locked within the positive nucleus of an atom. When scientific research workers learn how to tap and release this atomic energy, power which is very expensive at present, will be the cheapest commodity in the world. Truly there will be more power available than man will be able to use, for the volume of atomic energy waiting to be released is so great that it can only be calculated in astronomical figures.

TELEVISION

Television has already approached the point where it is leaving the laboratory and becoming a commercial reality. Another new industry is being created which will afford many opportunities to trained men. It will not be very long before television sets will be in use just as extensively as radio sound receivers are today.

Yes, television is now highly developed and is definitely here to stay. In several large cities television programs are already being put regularly on the air. And this service will be expanded as soon as several technical difficulties are overcome. Television receivers are now on the market and there are many homes already enjoying television entertainment. The pictures received by television sets have been perfected to such a degree that they are as clear and possess as much detail as the pictures obtained from many home movie projectors.

FACSIMILE NEWS TRANSMISSION

A late development in the radio field is Facsimile Transmission. Facsimile receivers are set up in private homes, and these reproduce the daily news in black and white print, complete with photographs, diagrams and even advertisements. The purpose of this service is to enable listeners to have permanent copies of the news, which is something that radio does not give, and to overcome the lack of detail which is characteristic of radio news broadcasts. This service now seems likely to become very popular, and, should its use become general, it will create many new opportunities for radio trained men.

The basic principles of radio are fast invading other fields, and new applications for them are being found almost every week. For instance, newly discovered electrical principles have found application in the moving picture industry and have made the talking picture possible. They are being used by the telephone companies to send the human voice across oceans. They are used in the new automatic selfself-levelining elevator systems in buildings. With the help of photoelectric cell equipment, we even find them counting automobiles passing through tunnels.

All wave sets, which enable you to tune in on any of the broadcast bands are rapidly becoming standard equipment. The general acceptance of all-wave, high fidelity receivers will make millions of radio receivers now in operation obsolete. All these older sets, sooner or later, must be replaced by newer, high fidelity receivers. With expansion like this before us, it is clear that more and more men will be required yearly to manufacture, install and service Radio and Television sets.

OUR TRAINING PLAN

You have been given, in the preceeding pages, a bird's eye view of recent scientific discoveries in the field of radio. You have learned that radio equipment of the future will involve new principles and will require the service of trained experts. You may have caught a glimpse of the countless opportunities soon to come in this field -- opportunities of large financial reward to men who are trained and prepared to take advantage of these opportunities. Now, you have made up your mind to achieve success in radio and you will wish to lose no further time before commencing detailed study of the fundamental principles. We know that you will be willing to study diligently to acquire this necessary knowledge and we know that you will find this study mighty interesting too.

If you were to study music -- say the art of playing the violin -- you would no doubt start with the very A, B, C's, and first train your fingers to execute the preliminary exercises dealing with the simple rudiments of music. Having mastered these, you would be prepared to advance to the next stage where you would practice the various musical scales. Finally you would be ready to undertake the more difficult musical assignments where considerable skill and perfected technique would be demanded of you. The same general principles must apply to the study of radio.

Since radio is based on electricity, we will commence the study of radio by first explaining the simple general principles of electricity and particularly those phases which apply to radio . Possibly you may have already learned these first principles and may feel that a study of these early lessons is a waste of time. In this case, note that we deal only with those explanations and topics which you will need in gaining a full understanding of your work later on. You may not understand why we spend so much time on details that may seem to have very little to do with radio, but remember that we are interested in your final success and this will depend to a great extent upon the knowledge you acquire from the study of these early lessons.

It is necessary to lay a "firm foundation " before you can proceed with the erection of a building upon it. The same is true of your training in electricity and radio. The first part of your training must form the foundation for all that will follow. The first assignments may appear to be very easy. Do not make the mistake of slighting these, or passing them over in a hurry. When you study some of the electrical laws you feel that you already know them, or that they seem to have nothing to do with radio, remember that we want to cover the whole ground without missing any of the essential details that may cause trouble later on. There is a definite reason why you are required to learn each topic discussed in your lessons. We are will acquainted with the problems you are going to meet. If we dwell on some de-

details at great length it is because we feel that these points will have a vital bearing upon your future work in the radio field.

STUDY METHOD

We are going to co-operate with you to the fullest extent for we want you to obtain the greatest benefit possible from this course. In order that this may be done we will outline here a few rules relative to your studies.

Set aside a given time every day, even if it is only a few minutes, and devote this time to study purposes. Do not let anyone interfere with this study period. Adhere to this schedule very strictly and do not put off your study with the excuse that you will study longer the next day.

Make a firm mental resolution to master perfectly the radio principles explained in each lesson. Keep in mind the fact that these lessons are only a means to a definite end. The goal you have set before you is a successful radio career, and all your efforts should be directed towards a speedy realization of this end. There may be times when your interest will wane and you may even be tempted to discontinue your studies, but if you have the inner conviction that radio work is your mission in life, we are sure that nothing will prevent you from attaining that goal. Your zeal and determination to succeed will enable you to counteract any negative influences tending to discourage you from completing your training.

When you receive a lesson read it carefully before looking at the questions. After you think you have mastered every point thoroughly then proceed to answer all of the questions without reference to the text. If some problem appears to be too difficult and you cannot answer it do not give up until you have made a real effort to arrive at the correct solution. If after several attempts you are still unable to get the correct solution write to us and we will give you the necessary explanations.

Remember that engineers and scientists have worked for many days on a single problem. Before the vacuum tube was invented many years were spent in study and experimentation. The same applies in the case of any great discovery or invention. Einstein, the renowned mathematical genius, sometimes works with problems which are so complicated that it actually is necessary to spend a whole week to perform all the necessary intermediate calculations before the final solution is reached. We do not want you to spend weeks or days at a difficult problem without asking for help, but we do expect that you will put a real effort towards finding the correct solution yourself. You will find that any such attempt will constitute an excellent form of training in itself which you would not acquire if you allowed some one else to do all the thinking for you.

Make up your mind definitely that you are going to become a radio engineer --and that under no circumstances will you permit this determination to be replaced by any less worthy ambition. It is a true saying that "There is always room at the top". We preach the doctrine of accomplishment, and the rewards of Success. Remember it is men with a backbone, not a wishbone, who achieve success.

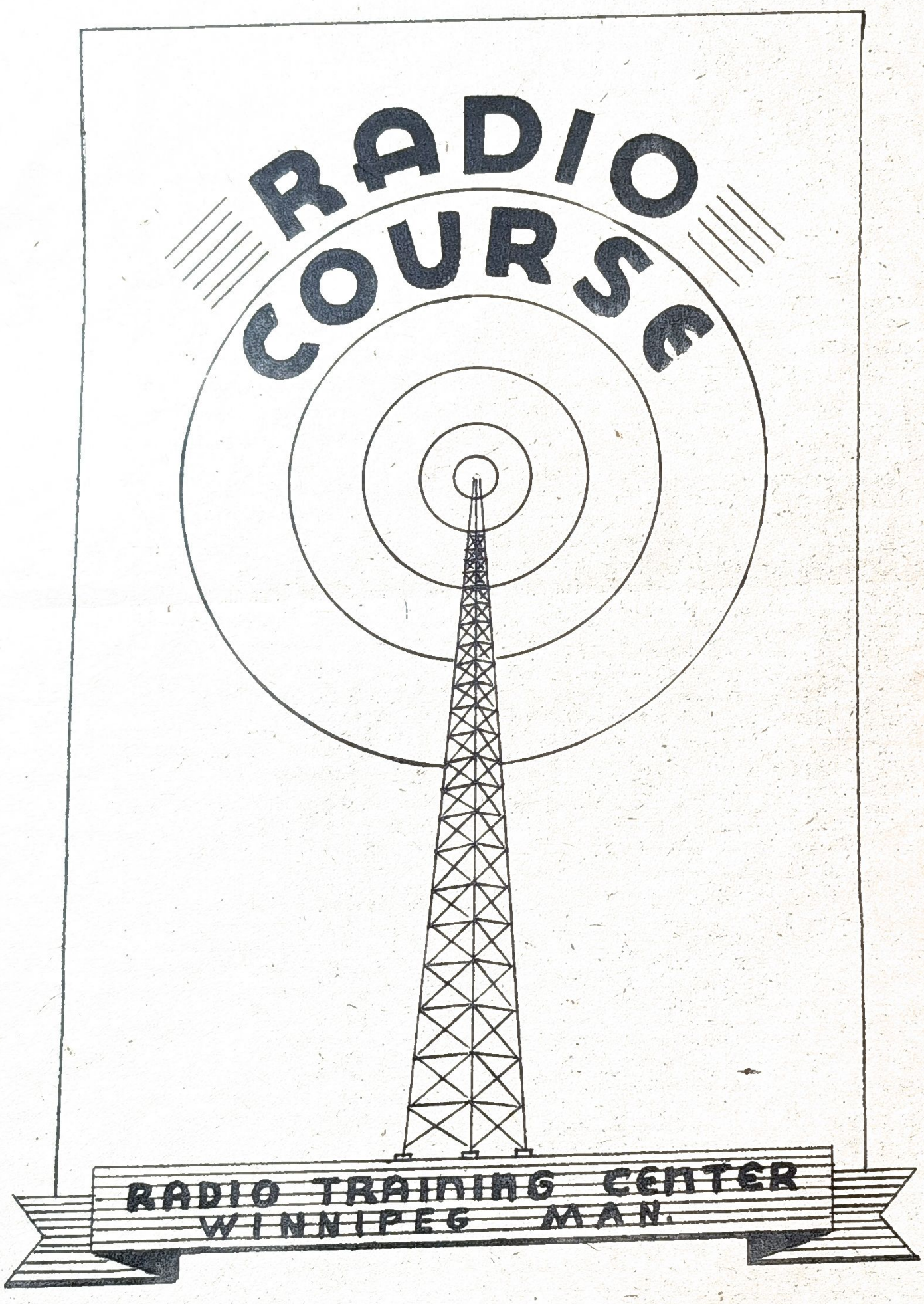
Your answers will be carefully analyzed by a qualified instructor. When in his opinion, you have mastered all the principles contained in the lessons studied, you will be sent further lessons. If you have made an error you will receive special instructions which will clarify the point that was not clear to you.

We have at our disposal all the necessary educational facilities to enable you to acquire easily and quickly the training you need. But it will be necessary for you to do your part and adopt our teaching plan, following all suggestions which we may make from time to time relative to your studies and progress.

This training has been specially prepared amd designed to conform to the needs of the busy individual who has only his spare time in which to study. Notice that we do not require you to finish a certain number of lessons in a given length of time. You will be permitted to study as fast or as slowly as you like. We only request that you devote a few minutes each day to the study of your lessons.

As a student you have enlisted our services, and you have asked us to make you a success in the Radio Field. We are sincerely interested in your studies and progress. We pledge you our best efforts towards giving you 100% co-operation and satisfactory service at all times.

And so we end our first lesson together. As this has been merely an introductory lesson you will have no questions to answer. In your next lesson we will commence the study of electricity in earnest. At the end of the lesson there will be a number of questions for you to answer and send in to us for correction and grading. We suggest that you send in your answers to these questions as speedily as possible, provided that you have obtained a complete understanding of the lessons. Never hold up one set of answers until you have completed another lesson. Most rapid progress will be obtained when you send in the answers to the test question of each lesson immediately after you have completed studying that lesson. In this manner, too, you will enable our instructors to watch your progress more closely, and to give you a more expert guidance throughout your training period.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LESSON TWO

Before we may discuss the subject of radio with any degree of intelligence, we must first have a fundamental knowledge of electricity and the laws which apply to electrical actions. For this reason this lesson will be devoted entirely to a consideration of electricity in its more simple forms -- what it is, how it acts, and why it can be made to do useful work.

EARLY ELECTRICAL DEVELOPMENT

The historical background of the modern science of electricity is very interesting and informative. Although there is no definite record of just when electrical activity was first noted, as far back as 200 B. C. scientists were familiar with the fact that amber when rubbed had the strange property of attracting and repelling light objects. And, because of this fact, the modern word Electricity has been derived from an ancient Greek word meaning amber. But it is to Dr. Gilbert, an English scientist of the 17th century, that the modern science of electricity owes its origin. Gilbert reviewed the knowledge of the ancients and experimented with their ideas, and, even though he did not produce any very startling results himself, the world must everlastingly be grateful to him for the opening up once more of a forgotten field of amazing knowledge.

Dr. Gilbert was soon followed in his research by a score or more of alert experimenters. Sir Isaac Newton and Gray experimented with various types of electrical machines designed to collect static electricity, i.e., to collect electricity produced by friction. Benjamin Franklin succeeded in collecting electricity from nature out of a thunderstorm by means of a kite and a large metal key. Galvani and Volta, early experimenters with chemical electricity, proved not only that there is a connection between chemistry and electricity, but also gave to the world the first practical method of making use of electricity. Up until their time, electricity had been a scientists hobby -- very interesting, but of little practical value -- but with the galvanic cell (the forerunner of the modern dry cell) and with the refinements produced by Volta in the voltaic cell, a practical means of utilizing electrical energy became available. Because of the experiments conducted by those men, electrical development along lines of telegraph communication and other simple applications, was well advanced before dynamos and electrical generators were even thought of.

THE ELECTRON THEORY

Scientists have long been struggling with the problem of what electricity really is. Many points have now been settled, but there is still a vast amount of knowledge which must be wrested from nature regarding this branch of science. However, sufficient is now known to make possible the widespread use of electricity, and to give a clear idea of what goes on inside an electrical conductor. Electrical flow, it is agreed, is caused by a motion of the electrons in a conductor. But to understand such a statement it will be necessary first of all to have an understanding of what an electron is, and how it can be moved about.

It is a standard theory in chemistry that all substances are products of the intermixture and combination, natural or artificial, and in various proportions, of items from a relatively small group of 96 "elements". These basic substances were termed elements because it was thought that they formed the basis of all matter, and as far as simple chemistry has ever been able to go, this theory is

perfectly true. But of more recent days scientists have discovered that by taking any element and breaking it up into very minute particles, eventually a point in size will be reached beyond which it is impossible to go without actually altering the composition of the specific element being considered. For instance, in taking a small piece of carbon and breaking it up into smaller and ever smaller portions, eventually the carbon will be reduced so small in size that it cannot be reduced further and still remain carbon.

The smallest unit of any substance which may exist is termed an atom. If it were possible to go beyond this and break the atom into its component parts, we would find that it consisted of electrons and protons. In taking a single atom of carbon and breaking it up, we would find that we no longer had carbon at all but simply so many electrons and so many protons. In taking an atom of any other substance and breaking it up also, we would find that it too consisted of electrons and protons.

According to the electron theory all substances are comprised of these units--electrons and protons--and it is believed that one substance differs from another only because the atoms of one substance contain either more or less electrons and protons than the atoms of other substances. The atom of hydrogen, for instance, contains only one electron and one proton, while the atom of lead contains some eighty-two electrons and protons.

According to the electron theory, an electron is a negatively charged particle, while the proton is positively charged.

An atom normally contains the same number of electrons and protons, and for this reason the total negative charge will be equal to the total positive charge, leaving the atom neutral. But the atom may also be made to assume either a positive or a negative charge. If the number of electrons contained in an atom is increased, then the atom will become negatively charged, and, conversely, if the number of electrons in the atom is reduced, the atom will become positively charged. Certain properties of the atom make this increase or decrease in the number of electrons possible, and it is upon this fact alone that electrical activity is based.

It should be mentioned here that whereas the number of electrons in any atom can be readily altered, the number of protons in the atom is always constant. If the number of protons in the atoms of any substance could be altered, that substance would be changed into something entirely different. Because of this fact, much research has been directed in an attempt to remove protons from the atoms of various substances. This branch of science is known as the science of transmutation, but unfortunately it has met with very little success. Possibly this is due to the peculiar structure of the ordinary atom in which it would seem that the protons are held prisoners by the surrounding ring of electrons.

The arrangement of electrons and protons in an atom is such that all of the protons are grouped into a compact mass situated at the centre. Into this mass is mixed about one-half or two-thirds of the total number of electrons, and the whole is termed the "nucleus" of the atom. The remainder of the atom revolve around this nucleus more or less as the planets revolve around the sun. This situation is depicted in figures one and two. In figure one is shown an atom of hydrogen. At the centre is a single proton around which

revolves a single electron. Figure two illustrates a more complex atom. In it the central nucleus will be seen to consist of a large number of positive charges (protons) with several negative charges (electrons) sandwiched in here and there throughout the mass. Around the nucleus revolves a second group of electrons, each electron in its own orbit, as indicated by the dotted lines. Notice carefully that the total number of electrons in the atom - that is, the number in the nucleus plus the number of free electrons floating around the nucleus --is exactly equal to the number of protons. Thus the complete atom will be charged neither positively or negatively, but will be strictly neutral, exerting no electrical force whatsoever upon surrounding objects. The free electrons which revolve here and there about the nucleus are not held rigidly to the nucleus, and may, under certain circumstances, be removed from the atom entirely. Actually the whole scheme of electrical activity arises out of the fact that these free electrons may be moved from one atom to another.

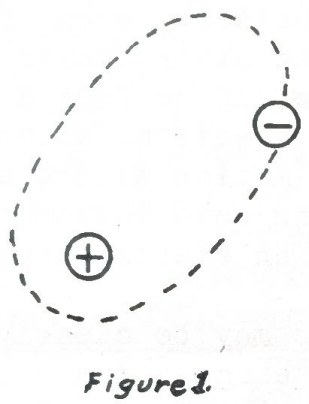
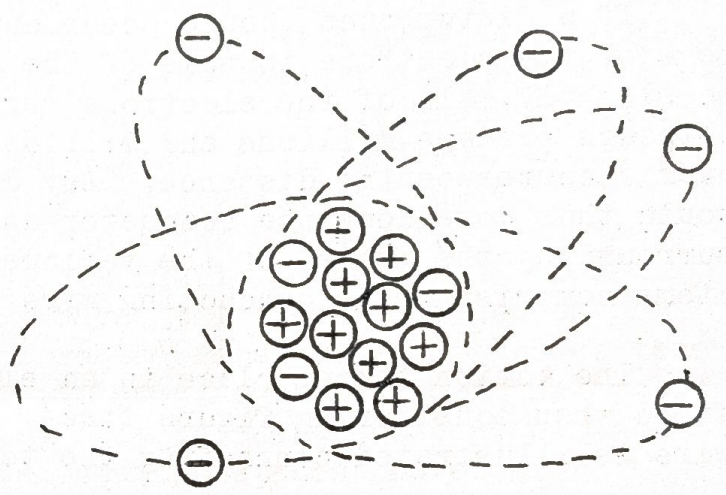


Figure 1.

Figure 2.



One thing further must be mentioned in regard to the structure of the atom. This is that the electrons and protons do not fill the whole interior space of the atom. Each electron is separated from the others, and from the protons, by spaces which are very wide when compared to the actual size of the electrons. The protons and electrons, even in the nucleus, do not touch each other, and all appear to be floating about in space.

The space in which the electrons float has been termed "ether" by scientists. It must not be confused with air, which is a gas and is therefore itself formed of atoms. Ether is simply the term given to the space which remains when all atomic substance (gas and other matter) has been removed.

THE NATURE OF ELECTRICITY

The electrons and protons from which atoms are formed, float about in space known as ether. They do not come into close contact with one another and would seem rather to be held by some force at a definite distance from each other. What this force is, is difficult to say, but a force does exist, for when one electron is jarred out of place, even very slightly, all of the other electrons immediately "move over", andmake room for it. Yet there is no apparent crowding, and no electron would ever seem to touch another. It is this force which holds the atom together, and in the nucleus it is very strong indeed.

Now the student will probably be wondering what all of this has to do with electrical flow, but actually there is a very definite connection. A copper wire, or other electrical conductor, is made up of millions and millions of atoms, each atom containing a nucleus surrounded by free electrons. These free electrons, although normally revolving around the nucleus of only one atom, exert a mutually repellant force not only upon the other electrons revolving around the same nucleus, but also upon the electrons revolving around the various other atomic nuclei. For this reason, to offer a very simple example, if all of the free electrons of one atom were moved to the left side of the nucleus of the atom, the free electrons of the adjacent atoms would likewise move to the left side of their respective nuclei, in order to keep at a constant distance from the electrons of the first mentioned atom. It is this tendency of the electrons to remain at definite distances from each other that makes an electrical flow possible.

If a disturbance should occur anywhere in a wire sufficient to cause some of the electrons in some of the atoms to change position, even if ever so slightly, all of the electrons surrounding all of the other atomic nuclei although perhaps millions and millions of atoms away, would be forced to move over a corresponding distance. Any disturbance of the electrons of any atom would thus move down the conductor as a wave of slight motion of the electrons surrounding the nuclei of the various atoms. It is this wave motion of the atoms comprising the conducting wire which constitutes an electric current.

The action taking place in an electrical conductor may be clearly understood when considering figure three. Here a very much exaggerated conducting wire is illustrated connecting the terminals of a six-volt storage battery.

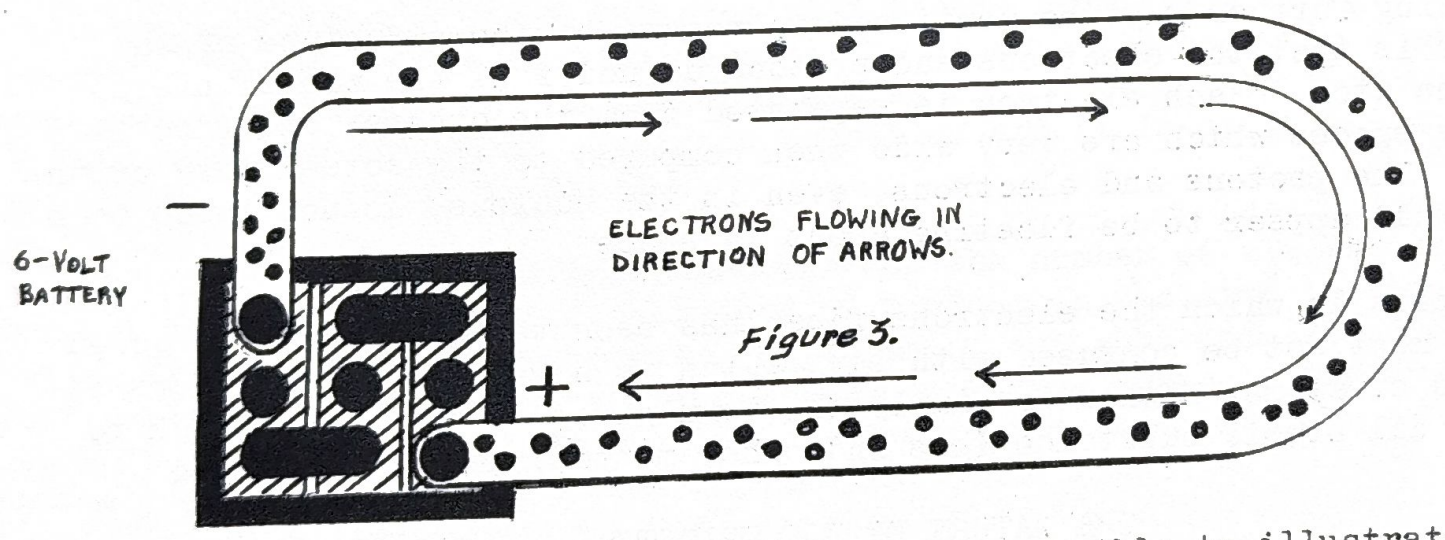


Figure 3.

The conductor is drawn large so that it will be possible to illustrate the electrons which partially form the metal of the wire. In the figure some of the electrons flow in a continuous circuit from the negative terminal of the battery, through the conducting wire, into the battery at the positive terminal, through the battery, and so back to the negative terminal, completing the circuit. Other electrons of the atoms of the metal retain their positions within the various atoms. These electrons do not add to the flow of electricity in the circuit, and so need not be considered. The free electrons of the atoms actually move from one atom to another, but because their movement is continuous, it is customary to consider that electrons flow through the wire in exactly the same manner as water might flow through a tube. This is the action which is indicated in figure three. Here we have disregarded the atoms with

their nuclei and whirling electrons and instead consider only the relatively few electrons which can be moved from one atom to another. Actually it is the movement of these "free electrons" which constitutes a flow of electric current.

An electrical pressure exists at the negative terminal of the battery, illustrated in figure three, and this pressure tends to drive electrons away from itself. These electrons move down the wire in the direction of the arrows, their direction being away from the negative terminal of the battery. An equal and opposite force will simultaneously exist at the positive terminal and this force will tend to draw electrons away from the conductor at the positive terminal. Because electrons are forced out at one battery terminal, and are drawn in at the other, a steady flow of electrons will take place in the conducting wire between the negative and the positive terminals of the battery.

There are several things more that should be considered before we leave the subject of atomic-electrical theory. The student will have been wondering whether or not the electrons of the conductor move steadily down the wire, or whether the electrical flow is merely a vibration of the electrons throughout the length of the wire. Actually both opinions may be considered correct. When the free electrons surrounding one atom are jostled, or shoved out of place, all of the other electron in all of the other atoms throughout the length of the conducting wire will be shoved slightly to one side. And in this manner the electrical disturbance, or wave, will reach the end of the wire, possibly thousand of miles away, before the first electrons which were disturbed have moved more than an atom or two away from their original positions. Thus it will be seen that electrical effects rush headlong down the conducting wire at immense speed while the actual distance traversed by a single electron is very slight. But, on the other hand, it is quite true that electrons do move along the conducting wire, from atom to atom, in the direction of current flow. This motion is much slower than the speed of the electronic wave, and as it is the electronic wave which produces all of the effects attributed to electrical flow, the speed of electric flow is considered to be the speed of this wave motion. This speed is 186,000 miles per second, and is so great that an electric current (the wave motion of the electrons in a conductor) will span the continent in less than 1/16 of a second.

ELECTRIC PRESSURE

Now that we have learned that an electric current may be set up disturbing the electrons at some point in a conducting wire, it will be necessary next to learn just how these minute electrons may be agitated and put into motion.

We know that a certain force exists between the various electron in the conducting wire, and that this force tends to hold all of the electrons to a definite distance from each other. From this it follows that if a force could be introduced into the circuit which would repel all of the electrons, these electrons would rush away from the repellent force, causing a current of electrons, or electricity, to flow in the conductor. This is quite true, but as it is impossible to increase the number of electrons in a conductor. If electrons are to be made to flow in at one end, other electrons must be allowed to flow out at the other end of the conductor. And these electrons must have

somewhere to go, for they will not fly off into space. For this reason, the agency pushing or repelling the electrons in one direction down a wire, must be capable also of drawing in electrons from the other end of the conducting wire. In a very simple electrical circuit in which a single long copper wire is formed into a loop with both ends connected to the terminals of a battery, electrons will be driven away from one terminal down the long wire, out the other end of the wire, and into the battery again via the other terminal. The number of electrons in the complete circuit will not be altered, and the battery in reality will act simply as an electron pump, sucking in electrons at one terminal and driving them out again at the other. Even when no external conducting path exists into which the battery may force electrons, the pumping action will not entirely cease. In this case the electrons of the battery terminals will be held under increased pressure at one terminal and reduced pressure at the other, and, as soon as an external conducting path is established between the two terminals, electrons will rush from the terminal at which high pressure exists, toward the terminal at which the pressure is low, in an attempt to equalize this difference of pressure. How a battery or generator creates an electrical pressure, or difference of potential as this pressure is technically termed, will be considered shortly. For the moment it will be sufficient if the student recognizes the fact that electrons are set into motion by the chemical action of the cell, and that this force produces an electrical pressure between the terminals of the cell capable of forcing electrons to flow in the connecting circuit.

A WATER ANALOGY

In our study of radio and electricity, we will find it very helpful if we always remember that we are dealing with a flow of electrons along a conductor and that this flow of electrons behaves, to some extent at least, as does a flow of water in a tube.

In figure four we have a circuit of water pipes. The rotary pump is rotated rapidly and sets up pressure at nozzel 1. This pressure causes water to flow along the pipe, through valve 2 and on to load 3. This load could be a water wheel set up to do useful work, deriving its power from the flow of passing water, or it might represent merely the opposition of long pipes to the passage of water. From the load water continues on through the pipe, arriving back at nozzel 4 of the pump.

Before we go on to consider the electrical counterpart of this circuit, several features should be carefully noted. The pump must be kept in operation all of the time in order that the water may be kept in circulation. Water is not used up in the process, and there will be the same amount of water in the circuit all the time. When the valve is open a continuous path exists through which the water may flow. But when the valve is closed, water will not flow in the circuit, no matter how much pressure may be developed by the pump.

If valve 2 is closed, the circulation of water through the pipes will cease, even though the pump continues to operate. The same pressures will be developed at points 1 and 4--a tendency will exist to force water out at 1 and to draw water in at point 4, yet no water will flow through the circuit because of the closed valve. If the pump is very large, and if the pressure built up between points 1 and 2 is great enough, then it is possible that the pipe will burst because of the excessive pressure.

With valve 2 open, and with the pump developing a definite pressure at point 1, a definite amount of water will be forced through the pipe during each second. If the speed of revolution of the pump is increased, the pressure developed will be greater, and the amount of water passing any given point in the circuit during each second will be increased. And it will be seen that the amount of water flowing through the pipes during each unit of time (seconnd minute, hour, etc.) will depend upon the driving force which has been applied to the circuit by the pump.

Now, perhaps we may want to regulate the speed of movement of water in the circuit. Suppose we wish the water to flow very slowly. By adjusting the valve opening we can regulate the rate of flow of water to any desired speed. If we close the valve to a narrow slit, then only a small amount of water will flow through. We can explain this action by saying that the small opening in the valve makes it harder for water to force its way through. If the valve is open wide, less resistance will be oppered, and a greater volume of water will flow.

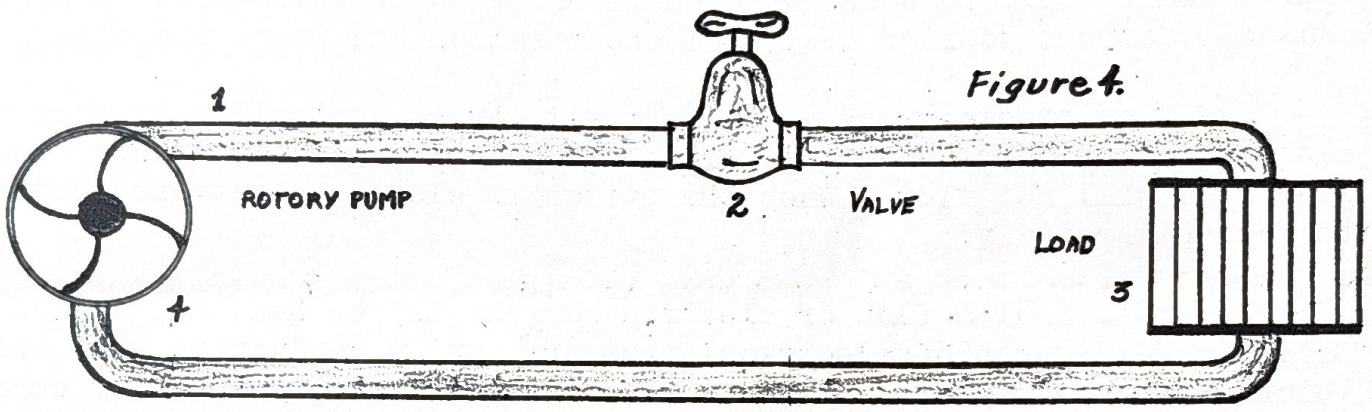


Figure 4.

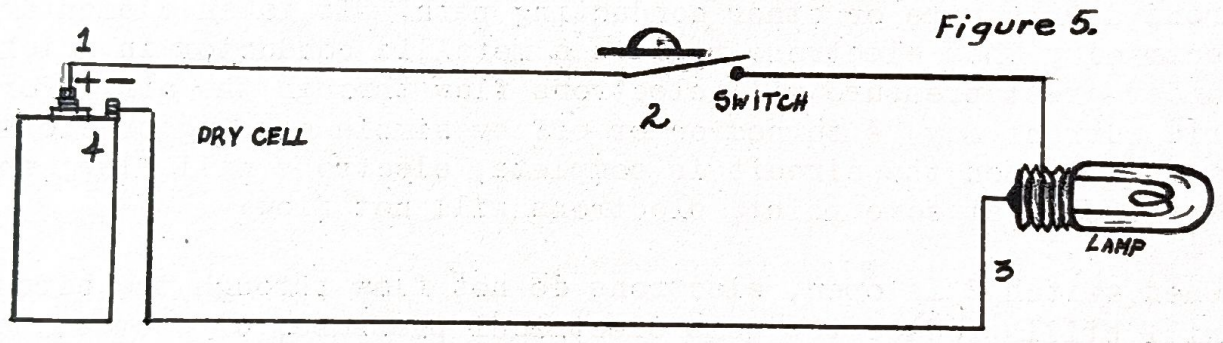


Figure 5.

The resistance which is mentioned here is the resistance of the narrowed valve opening only. But the complete circuit also offers resistance to the passage of water. If the pipe is large in diameter, then this resistance will be small. Or, if the size is small, then resistance will be large. If the resistance offered by the pipe to the passage of water should be variable, then by merely varying this resistance, the rate of flow through the pipes may also be varied. It is not easy to see how the resistance of the pipes of the simple water circuit illustrated in figure four may be altered at will, but we will assume that the resistance of the circuit in the section designated as the "load" will be possible. What will we expect to happen to the flow of water through the pipe, if the resistance of the load is suddenly made

greater? The amount of water getting through the load will be reduced, and the rate of flow in the circuit will decline. Thus the amount of water which will flow in the circuit will be seen to depend upon two things, the pressure developed by the pump, and the resistance offered by the pipe circuit.

THE ELECTRIC CIRCUIT

Now we are ready to consider an electric circuit. In diagram five we have the electrical counterpart of the water circuit illustrated in figure four. The dry cell takes the place of the rotary pump. It is so constituted that it creates an electrical pressure at its terminals--a force capable of driving electrons out at one terminal and capable of drawing other electrons in at the opposite terminal. To the terminals of the cell is connected a circuit which contains switch 2 and flashlight bulb 3.

The electrical pressure of the battery, known as electromotive force, or simply as "voltage", drives a current of electrons through the conducting wire in much the same manner as water was forced through the pipe in figure four. The battery produces an electrical pressure between its terminals which causes electrons to flow away from one terminal and in at the other.

The flow of electrons in the circuit may be controlled by opening or closing the switch. When the switch is open, the circuit is not complete and electrons will not flow. When the switch is closed, electrons rush around the circuit rapidly.

In order that a flow of electric current may be had, two things are necessary--a source of electrical pressure, and a conducting path through which electrons may flow. The source of electrical pressure may consist of a battery or generator, and its purpose is to create a force which will drive electrons down a wire or other conducting path. It is an elementary principle of electricity that electrons require a metallic conductor in which to flow. Only under great pressure will electrons flow through the air. For this reason electric current may be turned on or off by simple opening or closing theof the circuit. When the circuit is complete, electrons will flow; when it is open, or broken at some point, electrons will not flow.

When switch 2 is open, electrons do not flow through the circuit. The cell will still produce the same electrical pressure, of course, but electrons do not move because they are able to flow only in a complete circuit, not in a circuit that is broken at some point as this one is broken at the open switch. Closing the switch, a current flow will commence and the bulb will light up, indicating that an electric current is flowing through its filament.

Right here is a good place to make one matter clear. An electric current, unlike a current of water, can not be seen. Its presence and extent of flow must always be determined by some external means, such as heat, light, magnetic action, or through the use of specially designed meters. If no response is obtained in any of these ways, then we must conclude that no current is flowing through the circuit.

Comparing the circuit of figure five with the water circuit, we see that the pressure of the dry cell is forcing electric current through the circuit.

This current does useful work in the lighting of the bulb and current flow may be turned on or off by opening or closing switch 2. But in figure four we spoke of varying the amount of water flowing in the circuit both by altering the speed (and hence pressure) of the pump and also by varying the resistance of the circuit. Now we will wish to know if it is possible to alter the rate of current flow in the electrical circuit, and if so by what means.

The electrical pressure, or "voltage" of the circuit, is developed in the dry cell. This pressure will be constant in the circuit shown, but it can be altered in other circuits. If the voltage of a circuit is raised, the amount of current flowing will be increased in direct proportion to the increase in voltage.

But voltage is not the only factor in an electrical circuit which may be varied, and it is not the only thing which will affect the rate of current flow. The second variable factor is resistance. Just as the circuit of pipes in figure four offered a definite and calculable resistance to the passage of water, an electric circuit offers resistance to the passage of electrons. Resistance is a characteristic of every electrical circuit. No circuit has ever been built which contained absolutely no resistance, and some circuits contain very high resistance indeed. The actual amount of resistance contained in the circuit will depend upon several things, the most important of which are: (1) The length of the conducting wire (2) the average diameter of the conductor, and (3) the material from which the conductor is formed. All these will be considered again. For the moment we will be interested only in learning that every circuit has resistance and that the resistance of a circuit may be altered.

Although the resistance of circuit five cannot easily be altered, many circuits contain a device known as a "variable resistor" by means of which the resistance of the circuit may be adjusted.

Now, how will a change in the resistance of a circuit affect the quantity of current which will flow in the circuit? If a certain pressure is capable of driving a definite amount of current through a circuit of known resistance each second, and, if by increasing the pressure the amount of current per second may be increased, then it should be obvious that if the resistance of the circuit is lessened, current flow will increase. This is perfectly true. Current strength through any circuit depends upon two things: the resistance of the circuit and the pressure which is applied to the circuit. If resistance is reduced, current flow will increase, or if voltage is raised current flow will increase. The exact extent of the increase in current which will accompany any given change in the resistance or voltage of a circuit, is a very interesting subject, but we must leave this for careful consideration in a later lesson of the course.

TEST QUESTIONS

(1) What two men are credited with the development of the chemical cell to produce electricity from chemical action?
(2) Which was the first practical method of producing electricity, the chemical cell, or the mechanical electrical generator?
(3) According to the electron theory, what two articles form the atoms of which all matter is comprised?
(4) Describe briefly the structure of the atom.
(5) Do electrons normally touch each other in the atom?
(6) Are the numbers of electrons and protons in an atom normally equal?
(7) Is it possible to remove electrons from an atom?
(8) According to the electron theory an electric current consists of a flow of what particles?

RADIO
COURSE
RADIO TRAINING CENTER
WINNIPEG MAN.

LESSON THREE

SOUND & TELEPHONIC COMMUNICATION

In this lesson we will briefly outline the manner in which musical programs may be transmitted by wire from place to place, and how sound signals technically termed "audio signals", may be amplified and reproduced at any desired intensity,. This outline will cover a great deal of ground and so will touch only briefly on the workings of the apparatus encountered. More detailed explanations of these devices will be given in later lessons of the course.

In this and in the following lesson, we are going to trace a radio program from the broadcast studio, through to the sound reproduced in the radio set in your home. In this lesson we will consider only the operations dealing with sound, and the amplification of sound and audio frequency currents which take place in the broadcast station, while the actual transmission of a radio signal will be left for consideration in lesson four.

PROGRAM ORIGINATES AS SOUND

A radio program makes its first appearance as sound. This sound, produced by the artists at the studio, is picked up by a microphone, translated into a pulsating electric current, amplified, and finally used to modulate the radio frequency transmission which bridges the gap between the transmitter and your home. As sound is the first thing encountered, and is the thing which the radio in your home is expected to reproduce, it will be wise for us to consider first of all what sound is and how it is produced.

When a person talks, sounds are created which we hear with our ears. Sound in this case is a vibration of the air. In the case of human speech, the vocal cords of the throat set up a series of vibrations in the air within the throat and mouth. Changing the position of the lips and flexing the vocal cords in just the right manner, alters the characteristics of the sound being produced, and this is why articulate speech is possible.

The vibrating nature of sound may easily be understood by taking a sheet of stiff paper, and, while holding it lightly in the fingers, bring it close to a radio which is operating loudly. Sound waves, rushing away from the speaker of the set, strike the paper and set it into violent vibration. This vibration can easily be felt by placing the tips of the fingers lightly against the paper.

Sound travels rapidly outward from its source as a series of waves. If obstructions do not exist, it will usually travel equally well in all directions. The most common medium through which sound travels is air. The ordinary sounds which reach our ears are conveyed from their sources as a wave motion in the air.

Air, as you know, is a rather thin gaseous mixture consisting principallyof nitrogen and oxygen. The human vocal cords, or other sound producing apparatus, vibrate and set the surrounding air in motion. Air is a resilent, or springy compound. When the air nearest to the vibrating object is set into motion, the air particles at this point jostle and push upon other air particles slightly further away. These particles then set up a reaction

on other particles still further away, and, in t is manner, a wave motion of the air is set up which rushes rapidly away from the sounding object.

You are all familiar with wave-motion upon water. You know that when a stone is dropped into the surface of still water, a series of waves will be formed which will move away in all directions from the point at which the stone was dropped. Sound travels through air in a manner very similar to this, excepting, of course, that the movement is much more rapid, and, because the air is invisible, the wave motion is likewise invisible.

We are interested in sound here chiefly because sound activates the microphone at the radio station, and because sound must be reproduced by the speaker at the receiver. But how are these operations accomplished? A microphone contains a light, tightly-stretched membrain, or diaphragm. Sound waves, created by the performers in the studio, rush through the air and strike the diaphragm of the microphone, setting it into vibration. The diaphragm of a modern microphone is very light in weight. It consists usually of a sheet of a very tough aluminum aloy only one one-thousandths of an inch thick. So light are these diaphragms that they are set into violent vibration by even low sounds. A microphone diaphragm must respond in proportion to the intensity of the sounds they receive. A loud sound must cause the diaphragm to vibrate widely, while a lower sound must cause the diaphragm to vibrate to a lesser extent, and so on.

It should be pointed out here that sounds may differ in more than in their intensities. One person's voice differs from another person's voice even though both may be speaking at the same intensity, or loudness. A violin tone differs from that of a piano,or practically any other instrument, though all may be of the same intensity. Then, too, one key struck on a piano will sound differently from the note produced when another key is struck. And there is a difference between two dissimilar notes produced on the same violin. Two notes of a piano sound differently because they are of different pitch, while a note produced on a piano differs from a similar note produced on a violin for another reason. The tonal quality, or timber, of the notes produced on the two instruments is not the same. Many frequencies in addition to the basic frequency enter into each note, and these additional frequencies give the note its tonal quality.

There are three manners, then, in which two notes may differ one from the other. First, in intensity, or loudness. Second, in pitch, or frequency. And third, in the more subtle quality known as "tone" or "timber". These three characteristics of sound may be briefly summarized as follows: A loud note sounds loud because the waves of air set into motion by it are large and contain a lot of power, just as the waves upon a pond are lar ger when a large stone is dropped into the water, than they will be when a small stone is dropped. A note of a high pitch differs from a low pitched note because the frequency vibration of the sound wave set up by the high note is greater than the frequency of the sound wave set up by the low note. The term "frequency of sound" implies the number of vibrations which are set up per second by the sounding object. If the number of vibrations set up per second is high, then the note has a high pitch (or frequency), while if the number of vibrations is low, the pitch of the note is low. Now, for the third distinction, that of timber. Very few sounds produced consist of one frequency

only. A single note produced by a musical instrument might be considered as being a very simple sound. But even this note consists of a group of different frequencies acting together. The sound wave produced will thus contain ripples of various different frequencies. This group of frequencies, travelling together and striking the ear as one produce a combined effect upon our hearing which is responsible for the tonel quality or "timber" of the sound. A simple violin note contains a vast number of frequencies sounding together and it is because of this fact that it is readily distinguishable from a piano note, which contains a lower number of frequencies.

The wave form of a sound wave may be made visible by means of a device known as an oscillograph. Sound waves reproduced by such a device might appear as the outlines A and B of figure one. At A we have the wave form of a very simple note which contains only one frequency. At B is shown the wave form of a somewhat more complex sound. The pattern here seems quite jumbled. Actually it consists of a single low note to which has been added two or three higher frequencies. Much more complex sounds than this are possible.

Now, summing up what we have learned thus far, we know that sound is produced by vibration and is transmitted through the air as a wave motion. The frequency at which the sounding object is vibrating is responsible for the pitch of the sound. Sounds usually consist of more than one frequency. The number of frequencies which occur and the proportions in which these frequencies appear is responsible for the tonal quality. It is this latter quality which makes one sound readily distinguishable from another sound of the same basic pitch.

SOUND AND AUDIO FREQUENCY CURRENTS

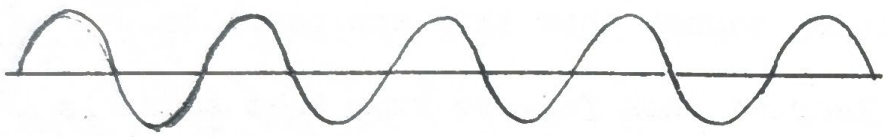
We want to make it very clear that sound itself does not travel from a broadcasting station to a radio receiver, or even from one end to the other of telephone wire. Real sound exists only at two points in a communication system--at the studio between performers and microphone, and again at the receiver. At all other points in the whole system we will be dealing with electric currents of one form or another, or with electro-magnetic waves.

The studio microphone is a device intended to translate sound wave motions into variations in an electric current. Sound waves produced in the radio studio strike the thin and very flexible diaphragm of the microphone and set it into vibration. The vibrations of the diaphragm of the microphone must be in exact proportion to the intensity and the frequencies of the sounds which strike it. It is important to note that the diaphragm of the microphone will respond to the combined effects of all of the sounds which strike it. Obviously it cannot vibrate in accordance with the frequencies of the sounds produced by any single instrument in a fifty piece orchestra. It must take all of the sounds together and vibrate in accordance with this combination. But this is exactly what we want, because the listeners too want to hear all of the instruments of the orchestra at once.

The outlines indicated at A and B in figure one are sound wave forms. What the microphone must do is produce a pulsating electric current of a form somewhat similar to this when complex sounds are striking its diaphragm. Now an electrical current of this form is produced in a microphone when sound

waves are striking its diaphragm, we will see shortly. For the moment we are going to consider this electric current a little more fully. It is known as an "audio frequency current" or simply as an "audio current". The word "audio" means audible, or something which can be heard. An audio frequency current thus is an electric current which pulsates with the wave form of some audible sound. In a radio receiver, or transmitter, we are very much concerned with audio frequency currents. The basic purpose of the studio microphone is to produce an audio frequency current having a similar characteristic to the characteristic of the sound which strikes the diaphragm of the microphone. The degree of accuracy which exists between these two indicates the quality of reproduction of the microphone.

When an audio current is fed to a telephone receiver, or to a radio loud-speaker, it activates a diaphragm, setting up sound waves which will have a wave form similar to the pattern of the audio current. As this current is similar to the wave form of the sounds which originally struck the diaphragm of the studio microphone, the sound reproduced by the speaker will be recog-nizable as the same as that which was produced at the studio.



A ONE FREQUENCY ONLY.

B SEVERAL FREQUENCIES SOUNDING TOGETHER

Figure 1

THE MICROPHONE

In figure two, the mechanism of one of the simplest types of microphone is illustrated. It is known as a "single-button carbon microphone". Although this microphone is not efficient enough for use in radio work, it is standard equipment on all household telephones. It operates in the following manner. Sounds striking the diaphragm cause it to vibrate. Attached to the diaphragm is a plunger, which, as the diaphragm vibrates, alternately compresses and releases pressure on the carbon granuals in the insulated box, or button B. The carbon granuals in the box are in series with the battery and the line, so that when the microphone is in use current continuously flows through them. As the diaphragm vibrates, the pressure on the carbon granules is varied in accordance with the sound waves which strike the diaphragm. As a change in the pressure of carbon granules also results in a change in their resistance, the strength of current going through the carbon is "modulated" or caused to fluctuate in accordance with the pattern of the sound waves striking the dia-phragm. An audio current is thus produced in the microphone.

A second type of microphone is illustrated in figure two. This is an "inductor dynamic" microphone, and is a type commonly used in radio work. This microphone works in a very different manner than does a carbon button microphone. The carbon button microphone merely modulates the current supp-lied from a battery. But the inductor microphone develops a voltage (or e.m.f.)

of its own, and so is the source of current in its circuit. For this reason no battery is included in the circuit.

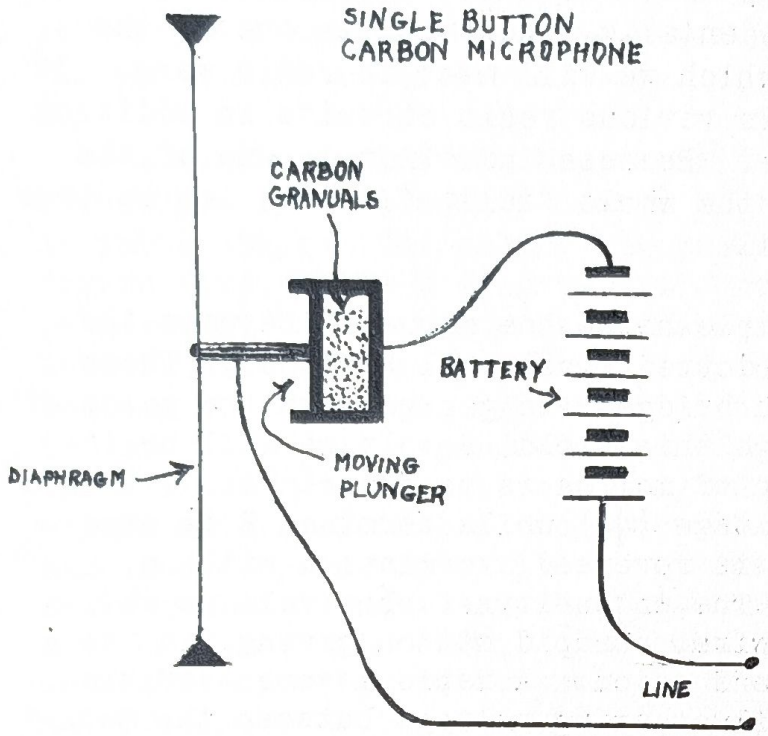


Figure 2.

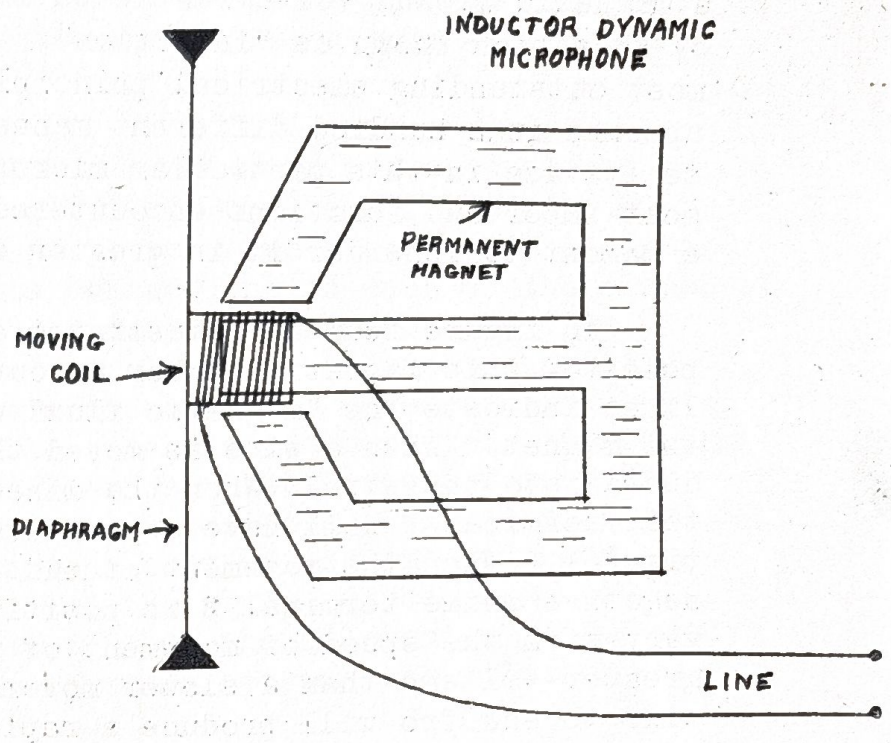


Figure 3.

Attached to the diaphragm of the inductor dynamic microphone is a coil of a very fine insulated wire, wound on an exceedingly light bakelite tube. The coil is suspended in the magnetic field which exists between the poles of the magnet which forms the body of the microphone. As the diaphragm vibrates the coil moves moves rapidly in and out through this magnetic field. This movement causes an electromotive force (voltage) to be developed in the moving coil. This electro-motive force causes current to flow in the coil and connecting circuit. The intensity of this current will, of course, vary in accordance with the extent of the movement of the coil and diaphragm. In this manner the inductor dynamic microphone also produces an audio current.

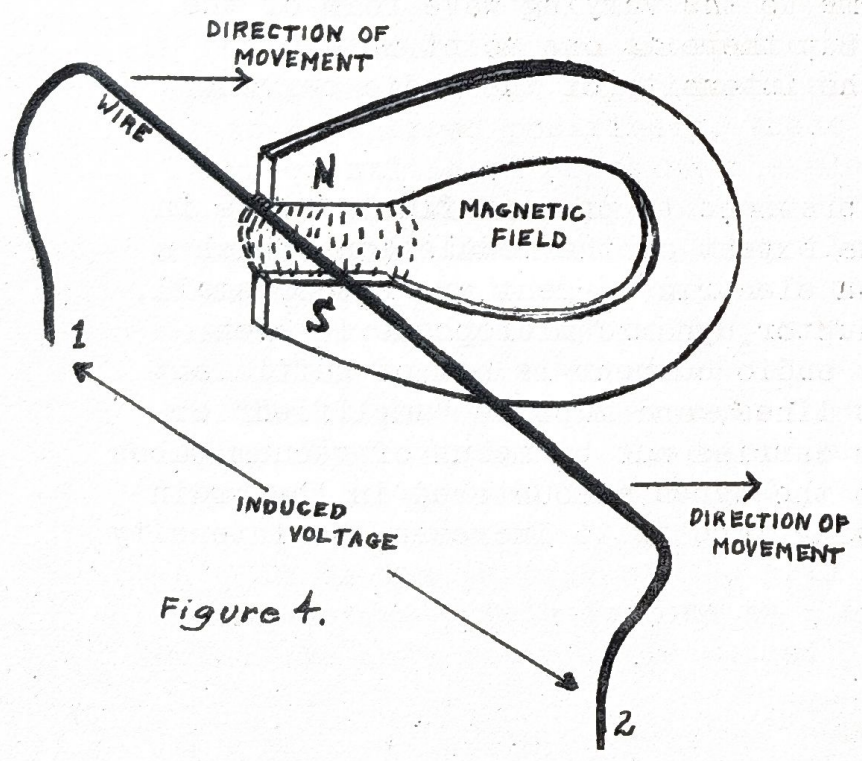


Figure 4.

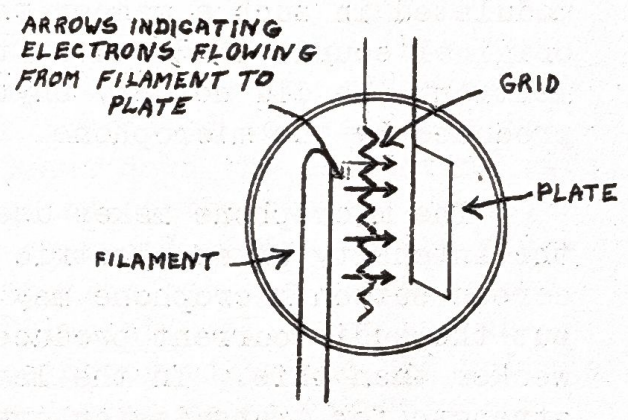


Figure 5.

The electrical principle upon which the operation of the inductor dynamic microphone is based, is known as "induction". When a wire is moved through a magnetic field, voltage will be induced into the wire, while it is in motion by an action known as "induction". Incidentally, induction is one of the most outstanding electrical principles which we will meet in radio work. It appears in a hundred different manners in various radio circuits in addition to its use in this particular microphone. Because induction is one of the most important functions encountered in the whole field of radio, let us take a moment to consider it in greater detail.

In figure four is illustrated a simple horseshoe magnet. Between the poles of this magnet a number of curved dotted lines will be noted. These lines indicate the "magnetic flux" which bridges the gap between the poles of the magnet. When a wire is moved through this field, a voltage will be induced into the wire. When the direction of motion is to the right, as indicated, terminal 1 will have a positive voltage (+) while terminal 2 is negative(-). When the movement of the wire is reversed, terminal 1 will be negative while terminal 2 is positive. The intensity of this voltage will vary with the speed of movement of the wire, a rapid motion giving rise to a greater voltage than a slower movement and so on. A rapid movement of the wire to and fro will produce a rapidly fluctuating voltage between the terminals 1 & 2. The pattern of this current will depend upon two things, namely, the speed of movement, and the extent of movement of the wire through the magnetic field. By moving the wire in just the right manner it would be possible to produce an audio current in it such as is produced in the moving coil of the inductor dynamic microphone.

Induction takes place in a variety of manners. A voltage may be induced into one coil as the result of varying the strength of current in another coil situated close by. The common radio, or power "transformer", is an induction device. In it power is transferred from one coil to another in just this manner, by induction. The working principles of a transformer will be considered in detail in later lessons of the course.

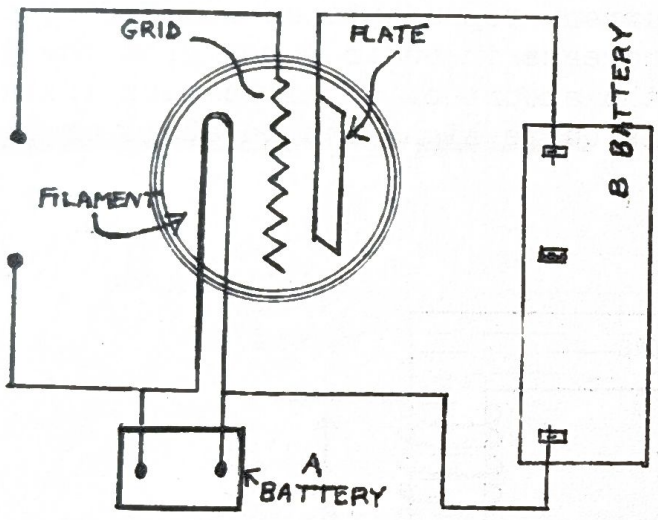
AMPLIFICATION

Returning now to the microphone, the first of the long chain of instruments through which a signal must pass before sound may be reproduced by the receiver. The output of the microphone, we have learned, is an audio current modulated in such a manner that it conforms to the varying wave form of the original sounds produced at the studio. But there is one point we did not mention. We did not say anything about the intensity of the audio current produced by the microphone.

The microphone makes use of sound vibrations to produce fluctuations in the intensity of an electric current. The extent of the modulations which a carbon button microphone may produce in an electric current are rather small, but the audio current produced by the inductor dynamic microphone is even weaker than this. In the latter case the audio current is not of sufficient strength for transmission over even short lines, and must be "amplified" or reinforced immediately. Amplification is carried out by means of vacuum tubes usually of a type more or less similar to the types encountered in the ordinary radio set. The purpose of an amplifying tube is to increase the intensity

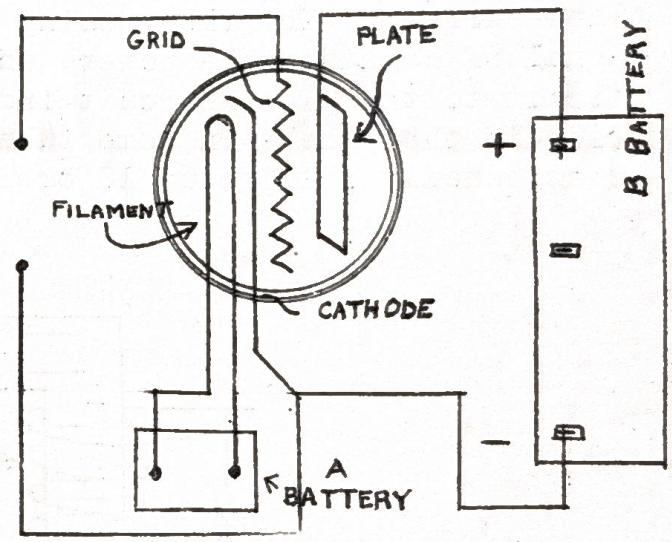
of the fluctuations of an audio current without distorting, or in any way altering the wave form of the current (or its modulation characteristic as this wave form is often called).

A simple amplifying tube contains three elements, or parts, enclosed in a vacuum. These elements are: a plate, a grid, and a filament or cathode. A symbol diagram indicating the positions of these three elements is given in figure five, while a diagram indicating the connections to each of the elements is given in figure six. The filament is heated by current from the "A" battery and this heating causes it to give off electrons in great quantities. Because of the vacuum of the tube, these electrons may be moved freely about in the tube. The second element of the tube, the plate, completely surrounds the filament. It consists simply of a cylinderical sheet sheet formed into a tubular shape. The plate invariably is charged positively with a high voltage in order that it will attract the electrons cast off by the filament. Between the filament and the plate is situated the grid. It consists of a mesh of light wire and it also completely surrounds the filament. It is used as a sort of valve to control the flow of electrons between the filament and plate.



FILAMENT TYPE

Figure 6.



CATHODE TYPE

Figure 7.

Electrons, as you know, are small negatively charged bodies. Heating the filament of the tube causes electrons to be cast off by it. Because the plate is charged positively, these electrons are attracted to the place in large quantities. Reaching the plate they are drawn down the connecting wire to the positive terminal of the "B" battery situated in the plate circuit. After passing the battery, they fly through the conducting wire to the filament again, completing the circuit. This current flow between filament and plate, through the "B" battery and back to the filament, will continue indefinitely and at a constant rate , which will be governed by the "B" voltage and the filament temperature. This current is referred to as the "plate current" of the tube. Plate current flow will usually be constant when no voltage is applied to the grid.

It is the purpose of the grid to modulate, or vary the intensity of the plate current. This is done by placing a varying negative voltage upon the grid. Because the grid is placed between the filament and the plate, when

it is charged negatively its negative charge will lessen the drawing force of the positive charge of the plate, as felt by the free electrons cast off by the filament. As a consequence, less electrons will reach the plate when the grid is negative and plate current will be reduced considerably. Varying the negative charge of the grid will result in a corresponding variation in the intensity of plate current.

Now, how does the vacuum tube act as an amplifier? Its purpose, we recall, is to increase the strength of an audio signal current. It is the valve action of the grid which makes amplification possible. If the audio frequency current which we wish to amplify is applied to the grid circuit in such a manner that it will cause the grid voltage to change from a high negative voltage to a lower negative voltage, in accordance with the pattern of the audio frequency current, it is clear that plate current will be varied in an identical manner. The plate current of the tube will thus be modulated with the same audio pattern. But it is necessary that the fluctuating plate current be of greater intensity than the audio current which is fed to the grid, otherwise the tube will not amplify. How is this increase produced? In the vacuum tube the grid is placed much closer to the filament than it is to the plate, and because of this fact, even a small change in the voltage applied to the grid will result in a large change in plate current flow. This is exactly what is needed if the tube is to act as an amplifier. If an audio signal is fed to the grid which will change grid voltage to the extent of about one volt, this one volt swing of grid voltage will result in a very large change in plate current. The fluctuating plate current represents an audio frequency signal of considerable power, and the increase in audio power from the grid circuit to the plate circuit indicates the amount of amplification taking place in the tube. In some tubes this is quite high, but in audio amplifying tubes usually only about 10 or 15 times.

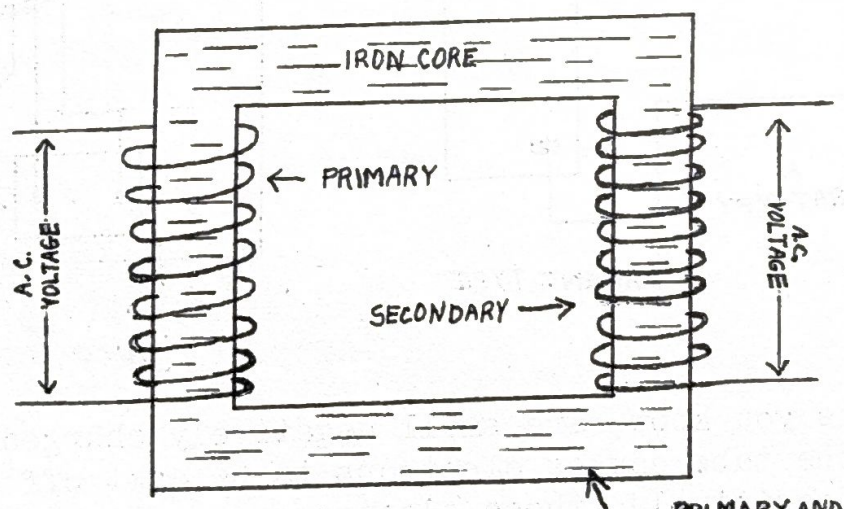


Figure 8.

Vacuum tubes are usually operated one following the other, and the amplified signal output of one tube is fed to the grid of the next, and so on. In this case full amplification will be the product of the amplification taking place in each individual tube. If the amplification in each of two tubes is ten, then the total amplification taking place will be ten timesten, or one hundred.

Amplifying tubes may be coupled together by means of transformers. A

transformer is a device consisting of two separate coils each containing a large number of turns of wire. The two coils are wound on an iron core and in such a manner that the iron core passes through the centre of each coil and forms a complete magnetic circuit surrounding both coils. The structural details of a simple transformer are indicated in Figure eight. The two coils shown are termed "primary" and "secondary" coils. When current flows into the primary, magnetic flux is set up in the core, and this flux flows through the secondary coil. The two coils are linked by this flux, and this is the only connection which exists between the two. If the current in the primary is a fluctuating current, for instance an audio current such as would exist in the plate circuit of an amplifying tube, then the flux set up in the core will be constantly varying in density. The varying flux flowing through the core will induce a voltage into the secondary. This voltage will be of the same wave form as the audio signal in the primary and consequently will produce an audio signal current in the secondary circuit.

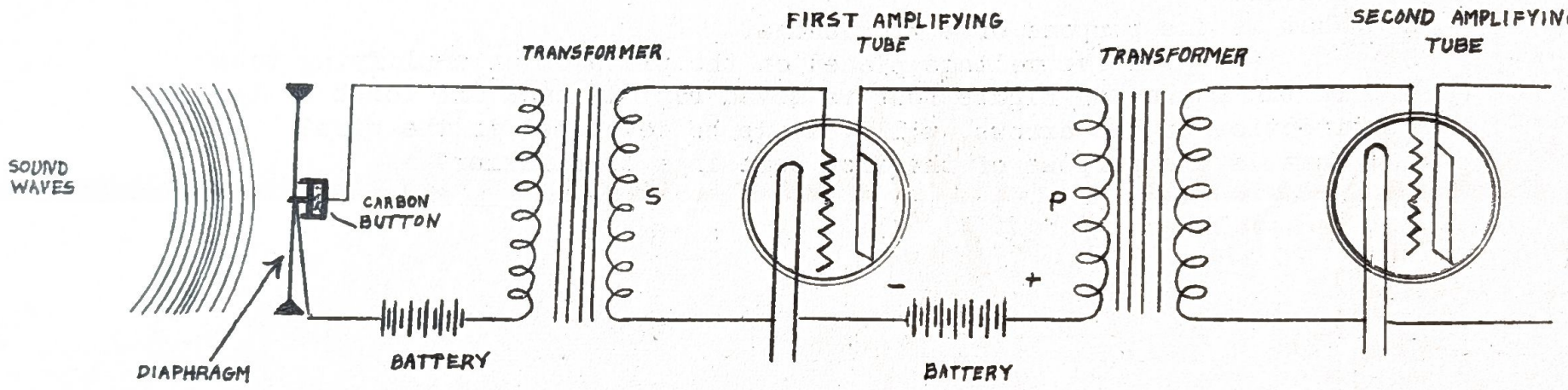


Figure 9.

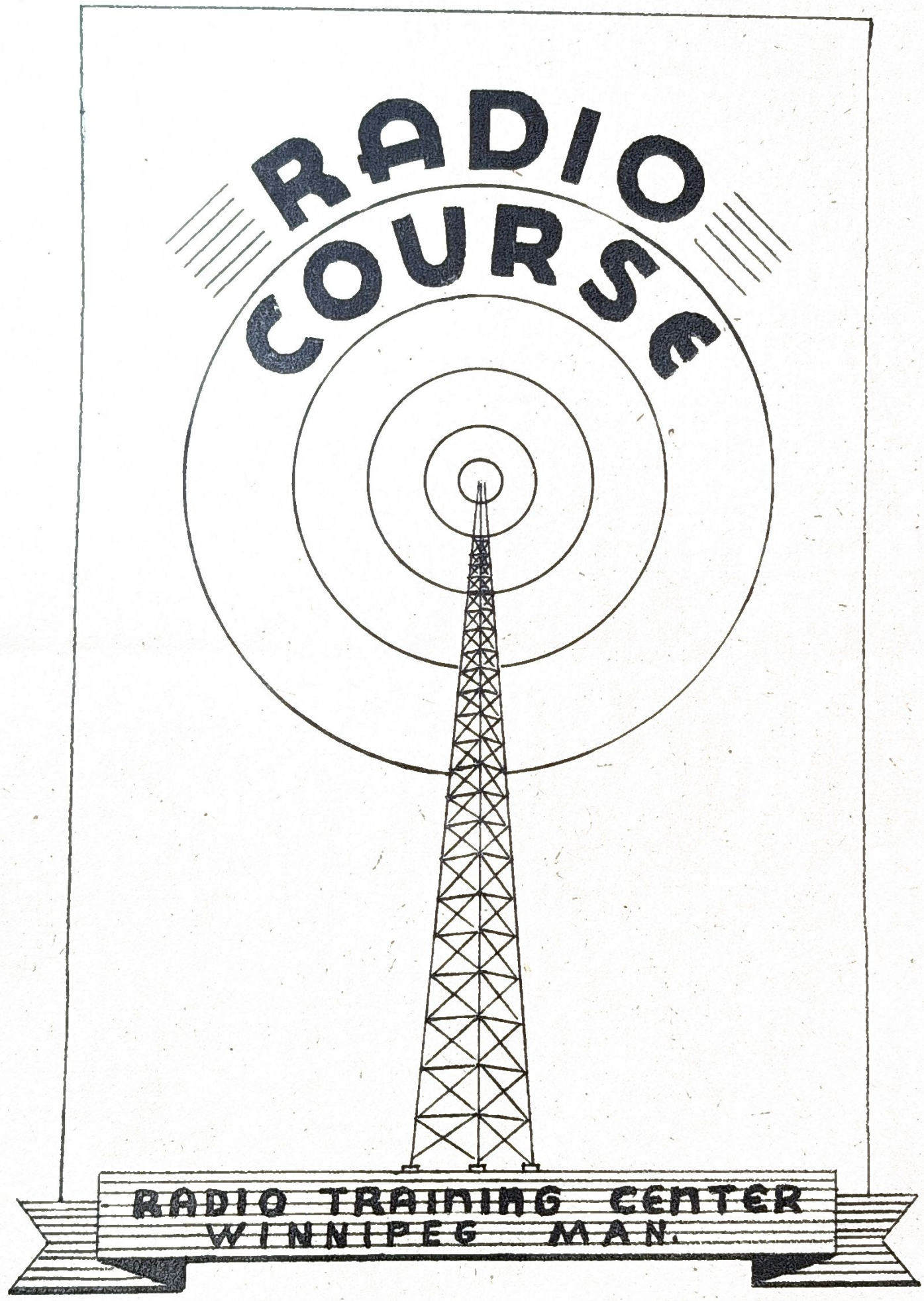
A microphone circuit consisting of a microphone and two stages of amplification is illustrated in Figure nine. Let us briefly consider the action taking place in this circuit. The diaphragm of the microphone is vibrated by sound waves, and the resistance of the carbon granules is varied in accordance with the sound wave pattern. Current flowing in the microphone circuit is modulated in this manner and emerges as an audio signal current. This audio current flows through the primary of the transformer which couples the microphone to the first amplifying tube. Varying flux is set up in the core of the transformer and this induces an audio signal voltage into the secondary coil. The voltage of the secondary is applied between the grid and filament of the following amplifying tube. The grid voltage will thus be impressed upon the plate current of the tube and an amplified audio signal will appear in the plate circuit. This signal current flows through the primary of the second transformer, and the actions just enumerated are repeated.

As indicated in figure nine, an audio signal may be amplified over and over again by vacuum tubes, until it reaches the desired intensity for transmission.

Transmission of an audio signal may be over land lines, such as connect the various radio studios on the continent, or it may be by radio waves. In the first case the action mentioned in connection with the amplifying stages of Figure nine is repeated, though the amplifying tubes may be separated by hundreds of miles of wire. But in the case of radio transmission, a series of radio waves are substituted for the land line, and these act as the carrier of the audio signal. Radio waves are produced by very high frequency a. c. currents of the order of several hundred thousand cycles per second, or more. These a. c. currents have the strange property of being able to develop electro magnetic waves in the ether, which radiate outward into space at the speed of light. Radio waves may be used to carry an audio frequency signal to the farthest ends of the earth. But how this is accomplished must be left for consideration in Lesson Four.

TEST QUESTIONS

1. Why will a paper held in front of a loudly operating radio be felt to vibrate?
2. What is the purpose of a microphone?
3. Why is a positive voltage placed on the plate of an amplifying tube?
4. If the magnet of Figure four is moved rapidly back and forth in the direction of the arrows, will voltage be developed in the wire?
5. What is the purpose of the iron core in a transformer?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LESSON FOUR

RADIO COMMUNICATION

In the last lesson we considered sound, and audio frequency currents, which are electric currents modulated to conform to the pattern of some sound wave. Audio frequency currents, we know, can be transmitted directly over wires, amplified and reamplified at various points along the route, and finally used to produce sound of the same form as the sound pattern which was modulated into the audio current at the microphone. The action here described is direct telephone communication, and it may be used to carry audio signals between any two points connected by a wire line.

But audio signals may also be transmitted over great distances between points that are not connected by wire lines, by making use of electro-magnetic waves, which are modulated in such a manner that they become the carrier of the audio frequency signal. But to understand how this is done, we must first consider an electromagnetic wave, and how it may be produced.

Electromagnetic waves are produced in the ether when a high frequency a.c. current is fed to the antenna of a transmitter.

The abbreviation "a.c." stands for alternating current, and an alternating current is an electric current which flows first in one direction, then reverses its direction of flow, doubling back on itself to flow for an equal length of time in the opposite direction. Most a.c. currents considered in connection with radio reverse their direction of flow rhythmically and at a more or less constant frequency.

Frequency is an important factor which must be considered whenever a.c. currents are dealt with, and this factor does not enter into direct current (d.c.) flow. One a.c. current may differ from another a.c. current in intensity, and also in frequency of alternation, but two d.c. currents can differ only in intensity. As the property of a.c. currents known as "frequency" is of very great importance in radio work, we will consider it a little more more fully here.

If the power line which serves your home is an a.c. line, the frequency of alternation almost certainly will be either 60 cycles per second, or 25 cycles per second, for these two are the accepted standards. But what does this term "60 cycles per second" mean? The current of the line flows first momentarily in one direction, and then momentarily in the opposite direction. The two pulses of current together are known as a "cycle". In a power line, one cycle follows another without pause, and the total number of complete cycles accomplished during one second is the frequency of the current in cycles per second.

A.c. of the power lines flows at the comparatively low frequencies of 25 and 60 c.p.s., but in radio work we are concerned with a.c. currents of frequencies up in the millions of cycles per second. For convenience a new term known as the kilocycle" is introduced to take care of higher frequencies. The prefix "kilo" is a Greek word meaning thousand, and the complete word "kilocycle" means simply a thousand cycles. An a.c.current of a million cycles per second may thus conveniently be referred to as a 1,000 kilocycle

current. For still higher frequencies we may use an even larger term, the "megacycle". A 10 million c.p.s. current can be spoken of as a 10,000 kilocycle current. But instead of using the term kilocycle we may speak of it as a "10 megacycle" current, for a "megacycle" represents a million cycles.

When you see the terms kilocycle or megacycle, you will know instantly that the current referred to is a.c., and of a frequency equal to the figure given, multiplied by 1,000, if given in kilocycles, or a million, if given in megacycles.

But now to return to the subject of electromagnetic waves. Electromagnetic waves, we said, are produced in the ether when an a.c. current of sufficient frequency is fed to the antenna of a transmitter. Not all a.c. currents will produce electromagnetic waves. If an a.c. current of a few hundred, or even a few thousaand cycles per second is fed to an antenna, it will not produce electromagnetic waves. Or, if electromagnetic waves are produced, these will be too weak to carry more than a few yards away from the antenna. But when an a.c. current of a few hundred thousand cycles, or a million cycles, per second, is fed to an antenna, quite a different situation arises. This latter a.c. current will have a high enough frequency to produce electromagnetic waves in the ether, and these will radiate outward into space to cover immense distances.

We will not need to concern ourselves with the actual structure of electromagnetic waves at this point. It is only necessary that you remember that electromagnetic waves are produced when alternating currents of high frequency are fed to the antenna of a transmitter. What we are principally interested in learning now is how these waves may be made use of in carrying sound signals from one point to another.

A simple broadcast antenna may be considered to consist of a single wire extended up into the air at one end, and down into the earth at the other. When high frequency a.c. is fed to this antenna, current surges rapidly up and down in the wire, between the peak of the antenna and the ground. This rush of current back and forth sets up a series of electromagnetic waves which rush outward into space, usually in all directions, at the speed of light (186,000 miles per second). If these waves in their flight through the air should happen to pass a receiving antenna (which is nothing more than another wire extending upward into the air and connected to ground at one end), they will induce an a.c. current into it. This current will have the same general characteristics as the a.c. current used to set up the electromagnetic waves at the broadcast antenna. The broadcast antenna and the receiving antenna may thus be likened to the primary and secondary coils of a very weakly-coupled transformer.

In the case of a transformer, varying magnetic flux is set up in a core when a.c. current flows through the primary winding. This varying magnetic flux in the core induces an a.c. current of similar pattern into the secondary winding. The only coupling which actually exists between primary and secondary, as you know, is the flux in the core, and for this reason the two coils are spoken of as being "inductively coupled" one to the other.

In a similar way the broadcast antenna is inductively coupled to the receiving antenna, though the action makes use of electromagnetic waves rather

than actual magnetic flux. Electromagnetic waves, and magnetic flux, however, have much in common, though in several respects the two differ widely.

When an a.c. current is fed to the antenna of the transmitter, an a.c. current of identical frequency will be induced into the antenna of the receiver. And, as the current induced into the receiving antenna will be proportional to the current flowing in the transmitter antenna, it will readily be seen that any series of rapid fluctuations in the intensity of the a.c. current fed to the transmitter antenna will produce a similar series of fluctuations in the intensity of the a.c. current induced into the receiver antenna. If the a.c. current of the transmitter antenna is keyed, --that is, broken up into a series of dots and dashes by means of a telegraph key--the a.c. current induced into the receiving antenna will be broken into dots and dashes of identical length and spacing. By this means, telegraphic communication is possible. Or, if the intensity of the a.c. flowing in the broadcast antenna is varied in accordance with some definite pattern, say, for instance, an audio frequency current, the a.c. current picked up by the receiver will vary in the same pattern. By this means it is possible to actually transmit sound signals from transmitter to receiver by means of radio waves.

RADIO FREQUENCY CURRENTS.

High frequency a.c. currents capable of setting up electromagnetic waves in the ether are known as "radio frequency currents". The term "radio frequency" is usually abbreviated "r.f.". So when you see the term "r.f. current", you will immediately visualize an a.c. current of sufficient frequency to set up electromagnetic waves.

R.f. currents are almost always produced by means of a radio tube employed in a circuit known as an "oscillator circuit", or simply as an "oscillator". In an oscillator circuit, the grid circuit of a vacuum tube is made to oscillate, or fluctuate at high frequency, with the result that a radio frequency current is produced in the plate circuit of the oscillator tube. This r.f. current is then amplified and fed to the antenna of the transmitter.

For reasons which we will consider later on in the course, it is necessary to keep all broadcasting stations operating exactly at their designated or assigned, frequencies. As the ordinary grid-tuned oscillator circuit tends to drift away from its proper frequency, it is scarcely suitable for use as the r.f. source in commercial transmitters.

Modern transmitters invariably maintain their frequencies by means of a vibrating crystal, usually cut from natural quartz. Crystals used in connection with oscillator circuits are ground flat on two surfaces, until they present the appearance of small round or square wafers, about the size of a postage stamp, or fifty cent piece. The crystals are opaque and the ground surfaces have the appearance of ground glass. The crystal, when in use, is placed between two flat metallic discs, as indicated in figure one. Notice that the crystal rests upon one plate and that an air space exists between it and the second plate. This air space, although somewhat exaggerated in the diagram, is actually necessary in order that the crystal may vibrate freely. A crystal vibrates in much the same manner as does a rubber ball.

The top surface may be pressed down slightly toward the bottom surface, and will push the two ends slightly outward. The movement, however, is so rapid, and of such slight extent, that it can not be seen.

The crystal, when vibrating, squeezes electrons out at the bottom surface, and draws them back in again, once during each vibration. The action here is very similar to what we would expect to happen if a wet sponge is placed between two boards and squeezed and released in rapid succession. When the sponge is pressed, water is forced out at the surfaces, and when the pressure is released, this water is drawn back into the sponge again. In the case of the crystal, however, electrons are forced out only at the bottom surface when pressure is exerted. The excess electrons squeezed out at the bottom, charge the bottom plate negatively. When pressure is released, these electrons are drawn back into the crystal, and a certain number of additional electrons are drawn from the plate. This causes the bottom plate to be charged positively, and the top plate negatively by comparison.

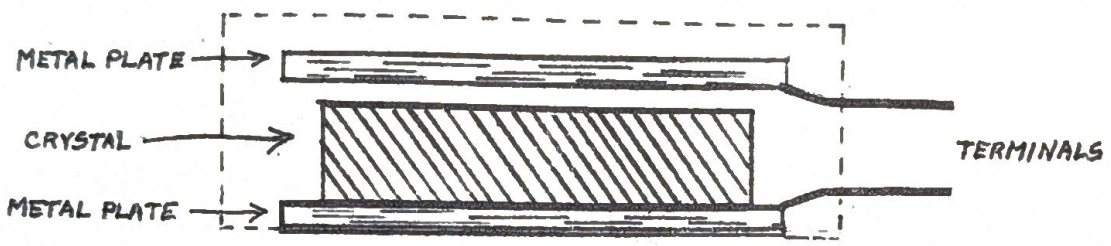


Figure 1.

So we see that when the pressure on the crystal is great, the bottom plate will be negative and the top plate positive. And when pressure is released, the bottom plate will be positive and the top plate negative. It follows, then, that when the crystal is set into regular vibration, an a.c. voltage will be developed between the two plates, and this a.c. voltage will of course, have a frequency equal to the frequency of vibration of the crystal.

The frequency at which a crystal will vibrate is determined by the thickness of the crystal, and for any single crystal is always constant, providing that temperature does not vary. Because a crystal vibrates to only one frequency, it may be used to stabilize the frequency of oscillation of the oscillatory circuit of a radio transmitter. By carefully grinding crystals to specified dimensions, it is possible to produce a crystal which will vibrate at the frequency at which any broadcast station is supposed to operate.

A vibrating crystal may be used, in connection with a radio tube, to produce a very stable oscillatory circuit. This type of circuit is known as a "crystal-controlled oscillator", and a typical example is illustrated in figure two. In this circuit the assembly of crystal and metal plates is connected to the grid, while the lower plate is connected to the cathode. The circuit operates as follows: When the crystal is set into vibration, an a.c. voltage is developed between its two metal plates. This a.c. voltage is fed to the grid of the vacuum tube, is amplified by the action of the tube, and

appears as an amplified a.c. voltage in the plate circuit of the tube. Part of the a.c. energy of the plate circuit is returned to the crystal, to maintain its vibration. (How this power is returned to the crystal will be explained later). The remainder of the a.c. energy of the plate circuit is led off by means of the air core transformer, is further amplified, and is finally fed to the antenna of the transmitter.

As the frequency of the a.c. current fed to the antenna of the transmitter will be the same as the vibrating frequency of the crystal, and as the vibrating frequency of the crystal is a constant, depending upon the dimensions of the crystal, it will be readily understood how it is possible to keep the transmitter operating at its proper frequency when a crystal controlled oscillator is used as a source of r.f. current.

The primary of the air core transform as illustrated in figure two has shunted across its length a variable condenser. The purpose of this condenser is to tune the circuit to resonate at the frequency of the a.c. current produced by the oscillator. We do not need to concern ourselves with how the condenser and the coil, which forms the primary of the air core transformer, may be tuned to resonate at the frequency of oscillation, more than to say that this is done by varying the position of the rotor plates of the condenser.

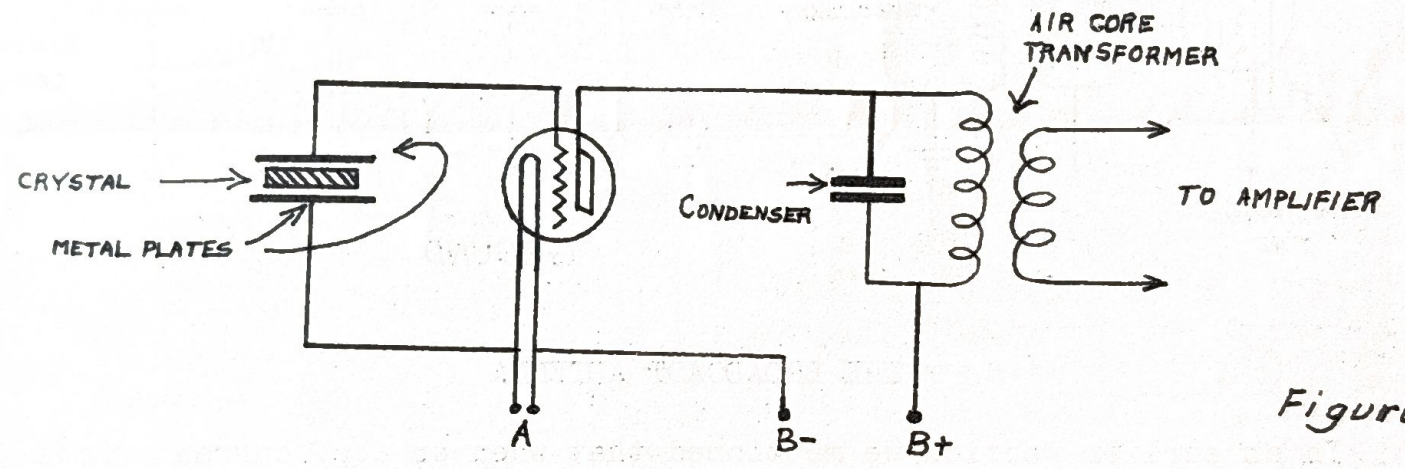


Figure 2.

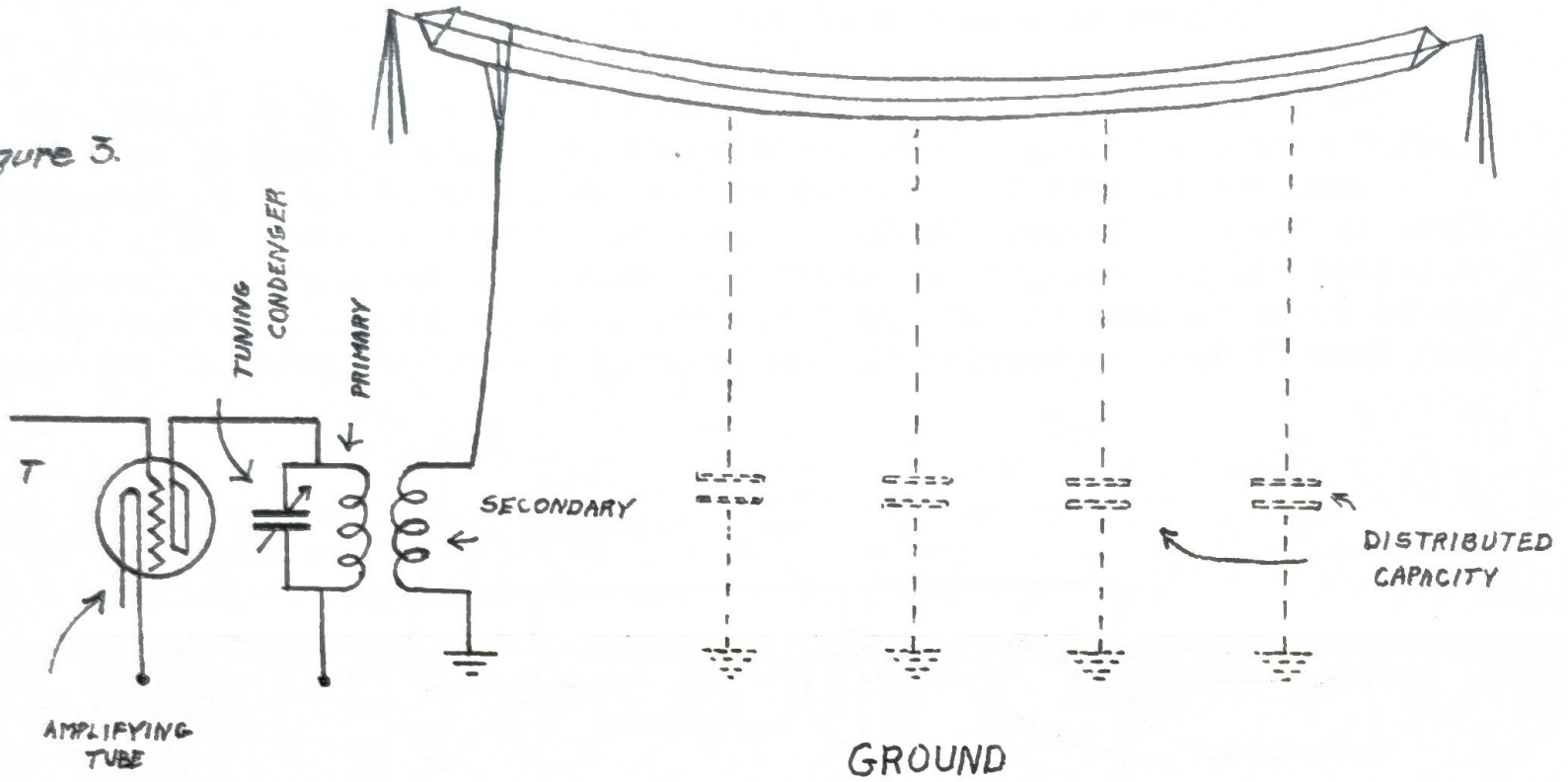
A radio condenser consists of a series of metal plates formed in two groups which interleaf one with the other. One group of plates (the stator) are held stationary, while the second group (the rotor) are mounted on a shaft so that they may be rotated in and out of mesh with the stationary plates. This rotating action varies the "capacity" of the condenser, and, in the circuit of figure two, varies the frequency to which the coil and condenser assembly will resonate. In figure two the position of the rotor plates of the condenser will be varied until the tuned circuit is brought into "resonance" with, or is "tuned" to, the frequency of the oscillator. When the circuit is in resonance to this frequency, the greatest amount of a.c. current will flow in it, and consequently more a.c. power will be passed on the following amplifying tubes.

The action taking place between the primary and secondary of the air core transformer illustrated in figure two, is exactly the same as the action in the transformer of figure eight of lesson 3. No core is used here because

the frequency of the a.c. current flowing through the primary is quite high and electromagnetic coupling will be carried on even without the aid of an iron core for the magnetic flux to flow in.

The coupling between coils carrying high frequency a.c. current is usually quite great, and the lines of force which accomplish this coupling often extend outward from the coils and link with other sections of the set, with harmful effects. In modern receivers this stray coupling between circuits is eliminated through the use of metal shields, in the form of cans, which completely surround coils, tubes, and other parts of the circuit.

Figure 3.



THE BROADCAST ANTENNA

In an earlier section we mentioned that when an a.c. current flows in an antenna, or wire suspended into the air at one end and grounded at the other, electromagnetic waves will be set up in the ether. We have considered how a high frequency a.c. current may be produced in an oscillator tube. Now, we must see how this current may be made to flow in the broadcast antenna.

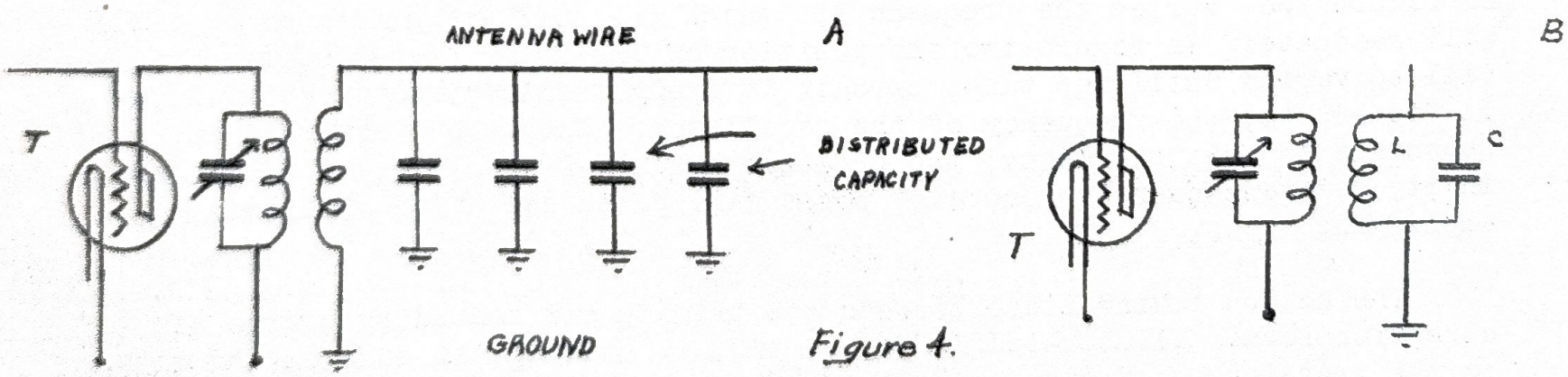


Figure 4.

In our discussion of electric circuits, we have always said that a complete circuit is necessary before electric current will flow. How then can a current be made to flow in the single wire of an antenna? The answer to this question is found in the fact that a.c. current can flow in a circuit containing a device known as a "condenser", even though actually no electrical contact exists between the plates of the condenser. Exactly how a condenser works will be considered later. For the moment you need only understand that it consists of two metal plates placed close together, but insulated from each other. When the two plates are connected into a circuit containing a source of a.c. e.m.f., current will flow, and the amount of this current will depend upon the size, or capacity, of the condenser. The capacity of a condenser depends upon the size of the plates, and upon one or two other factors.

The antenna of a transmitter forms one plate of a large condenser, while the ground forms the second plate. In figure three, a simple L-type antenna is illustrated. It consists of a long wire suspended high over the ground. In dotted lines we have drawn in a series of small imaginary condensers connected between the antenna and ground. These condensers represent the capacity of the antenna-ground combination, when used as a gigantic condenser.

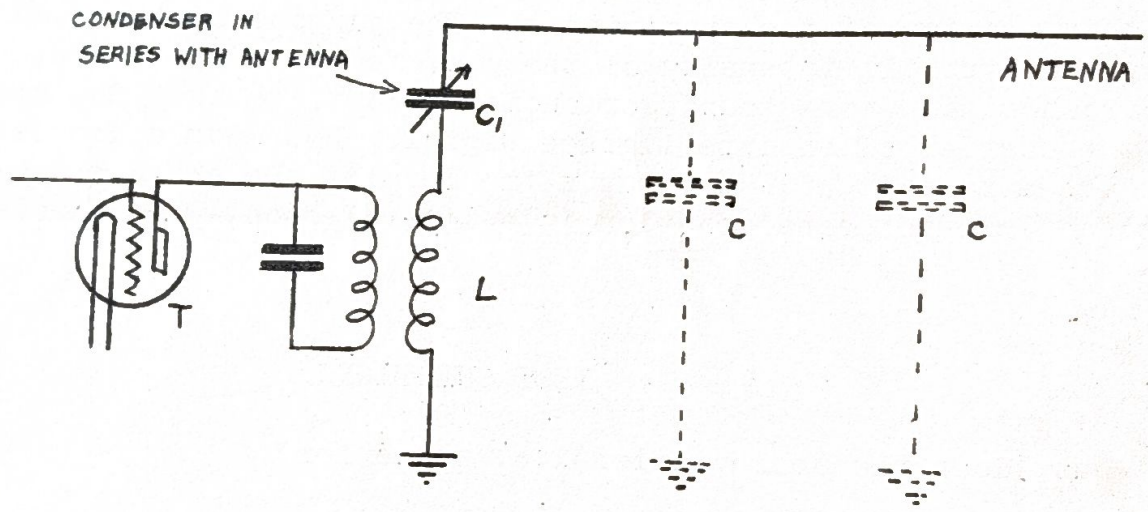


Figure 5.

In figure four A is illustrated a circuit which represents the exact electrical equivalent of the antenna circuit. It consists of a long wire connected to the ground through condensers at several points. The capacity of an antenna is actually distributed throughout its length in just this manner, and for this reason is known as the "distributor capacity" of the antenna.

The various condensers of figure four A are in parallel with one another by which we mean they are connected across each other so that they will serve the purpose of a single condenser of increased capacity, such as condenser C in figure four B. As far as simple electrical properties are concerned, then the antenna circuit of a transmitter may be reduced to the form of coil LC in figure four B. A.c. current may flow in this circuit, and when it does, it will result in an exchange of electrical energy between the coil and the condenser.

Circuit LC is a resonant circuit, just like the tuned coil in the plate circuit of tube T. Being a resonant circuit, it will respond to one frequency

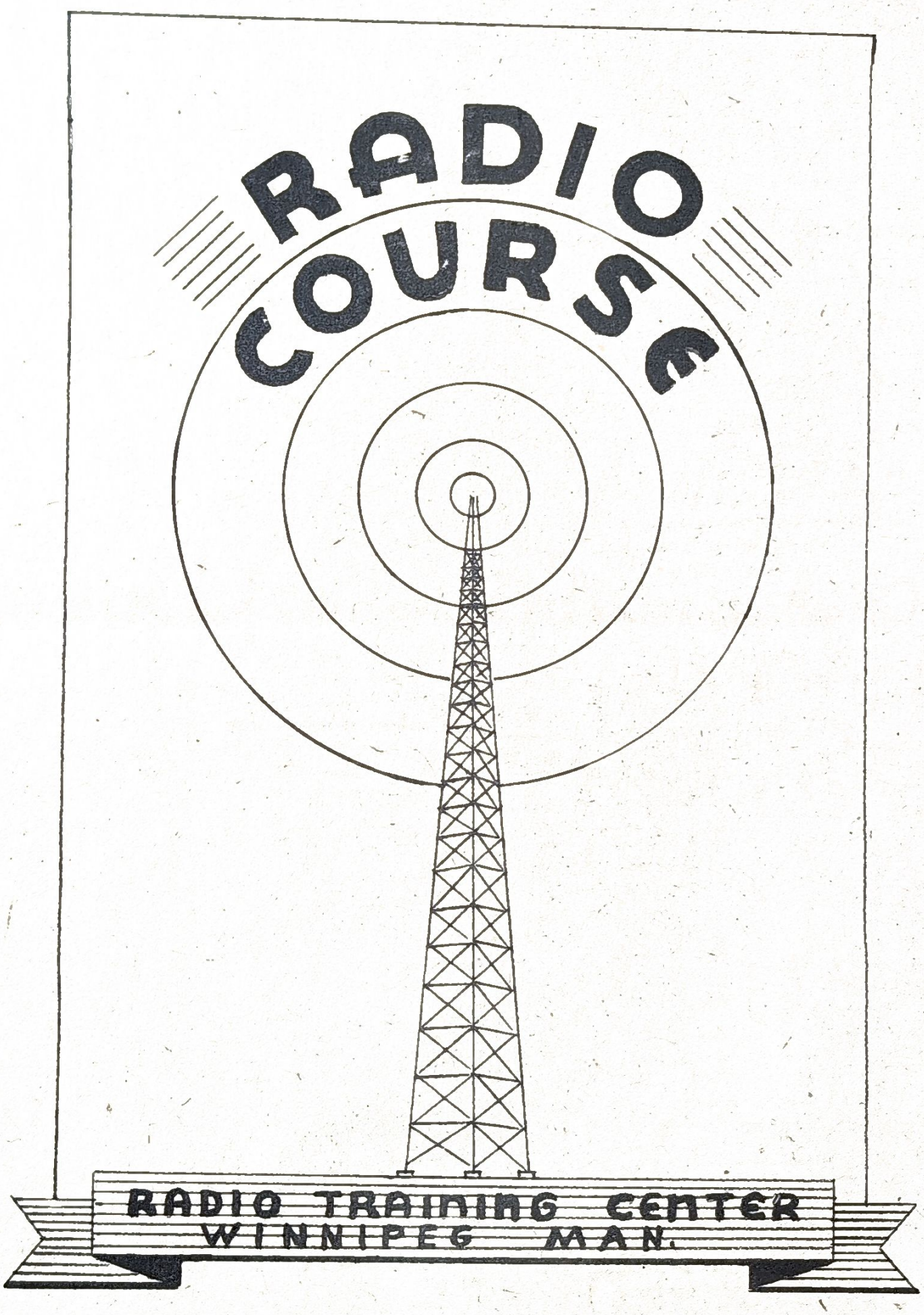
better than to any other, which means, of course, that more current will flow at that frequen cy than at any other. But the antenna is intended to carry a.c. current only of the frequency of the oscillator to which it is coupled. For this reason it is customary to tune the antenna to this frequency. This may be done by inserting a variable condenser (C1) in series with the coil and the antenna wire, as illustrated in figure five. Notice that condenser C1 is in series with the distributed capacity (C) of the antenna, and therefore all current flowing in the circuit must pass through condenser C1 as well as con denser C. Because of this fact, it is possible to vary the over-all capacity of the circuit by merely varying the setting of Condenser C1.

When C1 is adjusted properly, the maximum a.c. current possible will flow in the antenna wire. This current will surge backward and forward at the frequency of the vibrating crystal in the oscillating section, and will set up electromagnetic waves of similar frequency.

Between the oscillator and the antenna are situated several amplifying stages, the purpose of which is to boost the power of the a.c. fed to the antenna. In addition to amplifying stages, a modulator tube is also employed in this section of the transmitter. The purpose of the modulator tube is to vary the over-all intensity of the a.c. fed to the antenna, and in exact accordance with some sound, or audio current, so that the transmitter may act as the carrier of an intelligence signal. How modulation is accomplished and the effect it will have upon the form of the electromagnetic wave set up must be left for consideration in a later lesson.

TEST QUESTIONS

1. What does the abbreviation k.c. stand for?
2. What device is used in modern transmitters to control frequency?
3. What is the purpose of condenser C1 in the circuit illustrated in figure 5?
4. Will all a.c. currents produce electromagnetic waves?
5. Why are amplifying tubes needed between the oscillator and antenna circuits of a transmitter?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LESSON FIVE

HOW SOUND SIGNALS ARE CARRIED BY RADIO WAVES

In this lesson we are going to see how an audio frequency signal may be carried by a radio frequency current. We will study the actions which occur both at the transmitting end and at the receiver.

The action which takes place when an r.f. current is made to carry an audio frequency current, is known as "modulation", and the manner in which this is accomplished is illustrated graphically in figure one. In figure one A, we have illustrated a radio frequency current of constant intensity or amplitude, and, in figure one B, a single cycle of audio frequency current. To make the radio frequency current carry the audio frequency, all we have to do is mix the two together in such a manner that the amplitude of the r.f. signal will rise and fall in accordance with the pattern of the audio frequency signal. The result of this this action is illustrated in figure one C.

Looking at the individual cycles of r.f. current, we see that they are no longer of equal intensity. Some have increased while others have actually declined. Joining the peaks of r.f. current with a dotted line, we find that we have drawn a form similar to the cycle of audio frequency illustrated in figure one B. The dotted line indicated is known as the "modulation envelope" of the r.f. signal, and it must conform exactly to the pattern of the audio frequency current, if modulation is to be accomplished successfully.

The point that we want you to understand in connection with figure one, is that when an audio frequency current is impressed upon an r.f. current to produce modulation, the intensity of the r.f. signal must increase at the points where audio current is strong, and must decline at the points where audio current is weak, and the changes in the intensity of the r.f. current all along, must be in direct proportion to the intensity of the audio frequency current. Thus it will be seen that whereas a radio frequency signal does not actually carry an audio frequency current, its outline is moulded to the same wave form as the form of the desired audio frequency current. This moulding of an r.f. current to conform to the wave form of an audio frequency current, is spoken of as modulating an R.F. current to conform to the characteristic of an audio frequency current.

Modulation may be accomplished in the circuit illustrated in figure two. The circuit consists of a single amplifying tube, the grid circuit of which contains an r.f. transformer and an a.f. transformer in series with one another. When the circuit is in operation, the action which takes place is this: Unmodulated r.f. current of constant intensity is lead in through the r.f. transformer and applied to the grid circuit of the amplifying tube. At the same time the audio frequency current, which it isdesired to transmit, is lead in through the a.f. transformer, and applied to the grid circuit simultaneously with the r.f. The two currents then combine in the vacuum tube to produce modulation. The audio frequency signal, acting on the grid of the amplifying tube, causes the plate current of the tube to rise and fall slowly in accordance with the audio frequency signal. But, at the same time, the radio frequency signal acting upon the grid circuit, causes plate current to rise and fall rapidly, at radio frequency. The result is that plate current

attempting to follow both variations, rises and falls at radio frequency, yet at the same time the over-all intensity of this fluctuation will be varied at audio frequency. The plate current of the tube will thus be found to contain a modulated radio frequency signal in the form illustrated at figure one C.

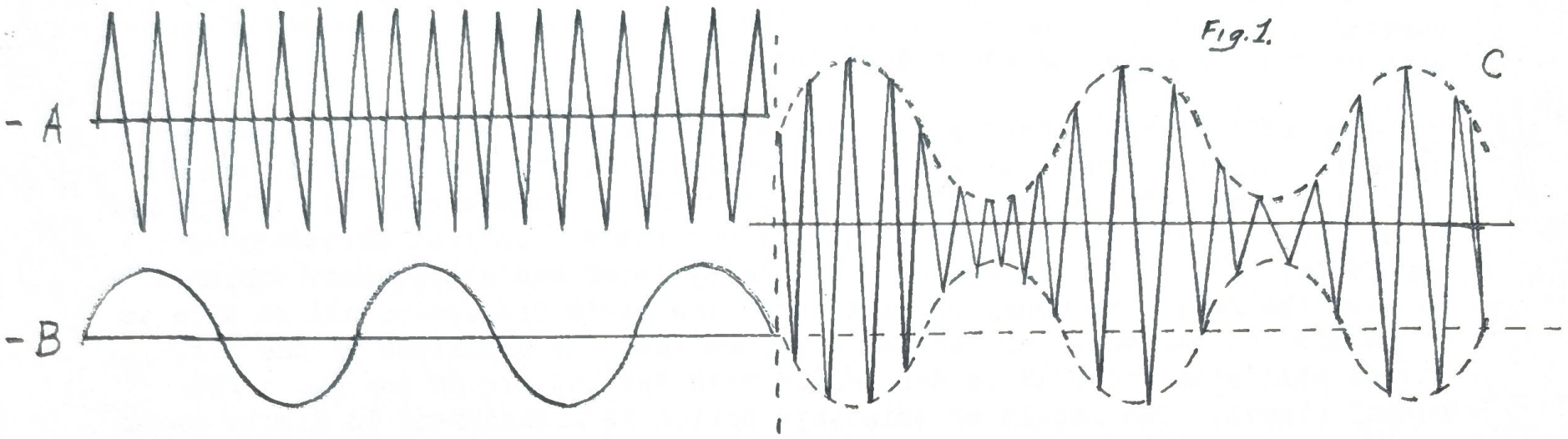


Fig. 1.

The modulated r.f. produced by the modulator tube of figure two, is led off, possibly reamplified through several stages of radio frequency amplification, and finally fed to the transmitting antenna. When this modulated r.f. current flows in the antenna, what will we expect to happen in the ether? Radio waves will be set up, of course, but these radio waves will no longer be of constant intensity. The waves which are now produced will be varying in strength, as well as vibrating at radio frequency, and it is this fluctuation in the intensity of the transmitted radio wave which represents the audio frequency signal.

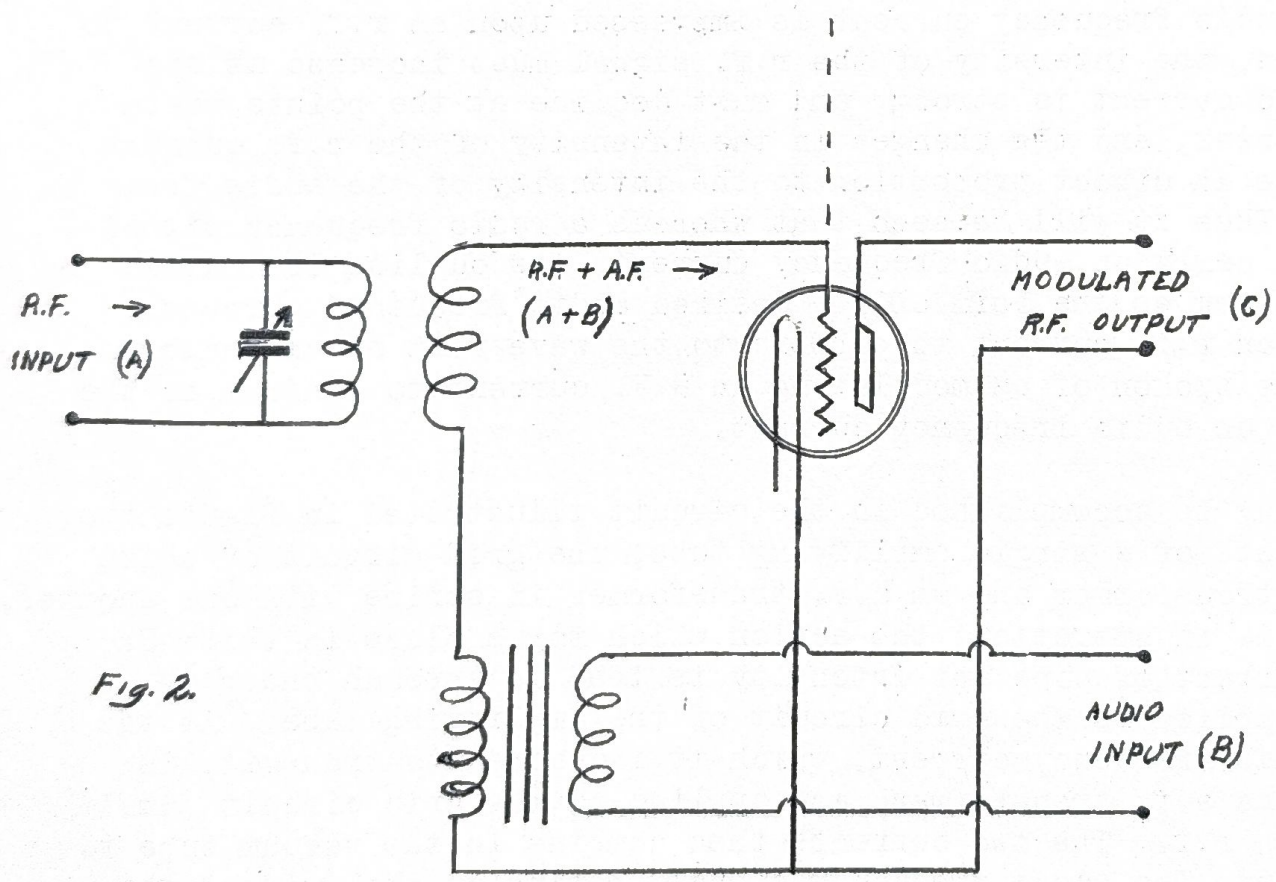


Fig. 2.

The processes which take place in the modulator of a transmittor may seem to be very complex to the beginner, and perhaps they are, but the purposes of these stages are quite simple, and the student will soon become just as familiar with them as he is with all the ordinary things in life.

RECEIVING THE R.F. SIGNAL

The electromagnetic waves set up by the broadcast antenna, radiate outward into space, and in their journey across the surface of the earth, come into contact with many thousands of receiving antenna. At each antenna, if the circuit is in resonance, an action takes place which is almost exactly the reverse of the action which took place at the broadcast antenna.

Electromagnetic waves consist of an electromagnetic field of force. When this field of force reaches a receiving antenna, it will immediately induce an alternating current into it, if it can. If an antenna circuit is adjusted to resonate at the frequency of the passing wave, the current induced into it may be of considerable intensity. If the antenna is not in resonance, then the induced current will be much weaker.

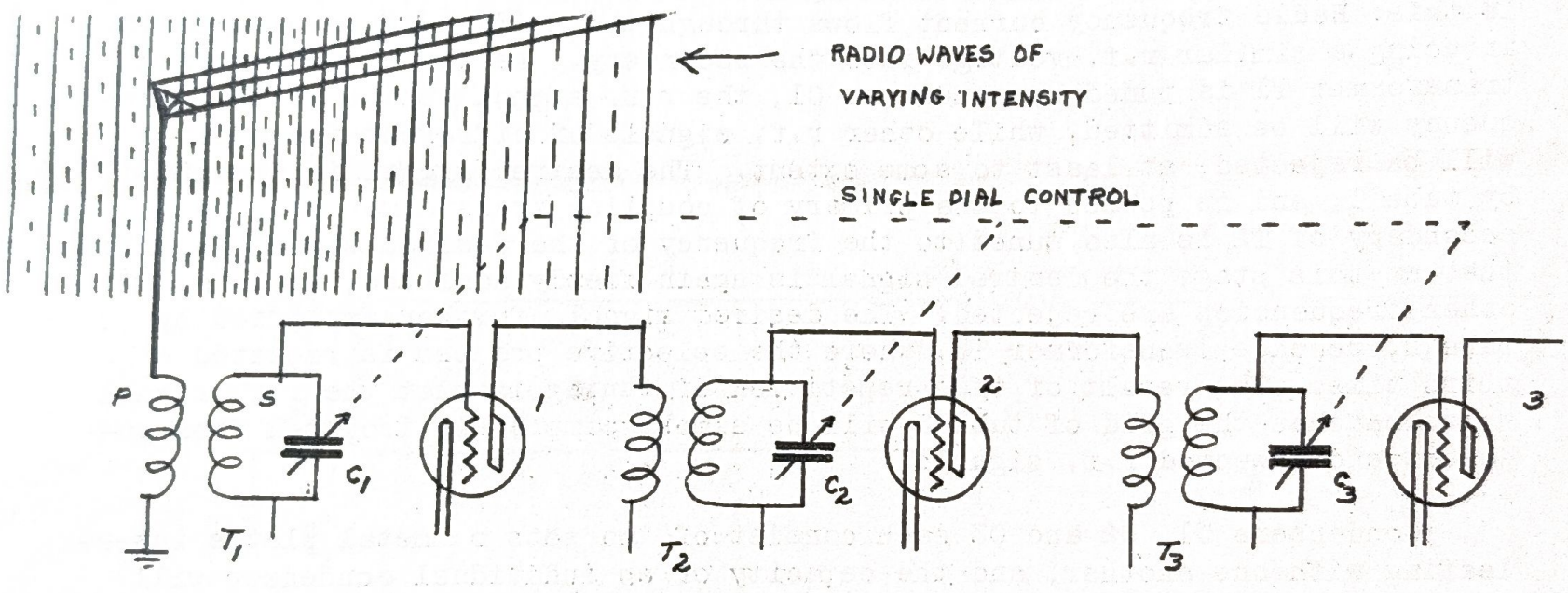


Figure 3.

The r.f. section of a typical radio receiver is illustrated in figure three. The antenna circuit here leads down to the primary of the first r.f. transformer, the secondary of which is tuned with a variable transformer. The antenna circuit would not appear to be tuned in any manner, though actually a certain amount of tuning is accomplished in one or other of two manners. First the antenna circuit may be designed to resonate to the average frequency which the receiver is intended to pick up, and second, tuning the secondary of the antenna coupling transformer will have the same effect as directly tuning the antenna circuit, because of a reflected action between the primary and secondary coils. But we do not need to worry about this matter at the present, more than to say the antenna circuit is always tuned at least approximately to the frequency of the desired signal.

An r.f. current of frequency equal to the frequency of the passing electromagnetic wave is set up in the antenna circuit. This current will surge back

and forth between the antenna and ground, passing through the primary of the antenna coupling transformer, and a similar r.f. current will be induced into the secondary. The secondary circuit is tuned and is connected to the grid of the first amplifying tube. In this tube, the r.f. voltage will be amplified, and will appear as an increased r.f. voltage in the plate circuit of the tube. The plate circuit contains the primary of coupling transformer T2. The secondary of this transformer is connected to the grid circuit of amplifying tube 2, in which the r.f. signal is further amplified before being led on to tube 3. Tube 3 may be a third amplifying tube, or it may be the detector, but in either case the external coupling to the tube will be of the form illustrated in figure three.

The inter-stage coupling transformers T2 and T3, and the antenna coupling transformer T1, are tuned by variable condensers C1 and C2 and C3, to give the set its selectivity. Condensers C1, C2 and C3 are pierced with arrows in the diagram, and are connected by dotted lines. This symbol indicates that the three condensers are variable by means of the same control, to give the set single dial control.

The combined action which takes place in the radio frequency amplifier, is this: Radio frequency current flows through the primary of transformer T1, inducing a similar r.f. voltage into the secondary. As the secondary of transformer T1 is tuned by condenser C1, the r.f. signal of the desired frequency will be admitted, while other r.f. signals of different frequencies will be rejected, at least to some extent. The desired signal is amplified by tube 1, and is passed to the primary of coupling transformer T2. As the secondary of T2 is also tuned to the frequency of the desired signal, we find that at this stage the desired signal is again freely admitted, while all other frequencies are rejected. The desired signal, further amplified by tube 2, reaches transformer T3, where the selective process is repeated a third time. The result of this repetition of tuning is that the r.f. signal which reaches the grid of tube 3 will be almost completely isolated from adjacent and unwanted r.f. signals.

Condensers C1, C2 and C3 each consist of two sets o metal plates interleafing with one another, and the capacity of an individual condenser will be changed when one group of plates is rotated in or out of mesh with the second group. The two groups of plates are known as the "rotor" and the "stator", because one group is rotated in and out of mesh with the other. When the rotor is entirely in mesh with the stator, the condenser is set at maximum capacity. When the rotor is entirely out of mesh with the stator, the condenser is at minimum capacity. Moving the rotor to any position between these two extrmities will permit adjustment of the capacity of the condenser to any desired valve.

We said that the capacities of the three condensers are all adjustable from one control. When they are rotated, this is the action which will take place: Supposing that a certain broadcasting station is setting up a strong radio frequency signal which is continuously passing the antenna, inducing at least some current into it at all times. This current flows through the primary of transformer T1, but is not admitted into the secondary because condenser C1 is out of tune with the signal frequency. As the three condensers are rotated across the dial, the secondary of transformer T1 gradually draws

into resonance with this signal. When it reaches the point of resonance, the signal finds that the secondaries of T1, T2, and T3 are all resonating to its frequency. So it instantaneously rushes through not only one tuned circuit but all three, to reach the grid of tube 3. This action explains why a strong signal may be tuned in and tuned out again on a modern receiver by merely moving the dial setting one or two points.

It should be borne in mind, then, that each stage of radio frequency amplification in a radio receiving set actually fulfills two functions. Firstly, it amplifies, or increases the strength of the received r.f. signal, and second, it adds to the over-all selectivity of the set, for it should be quite clear that as the number of stages of radio frequency amplification employed is increased, the better the selectivity of the receiver will become.

Fig. 4.

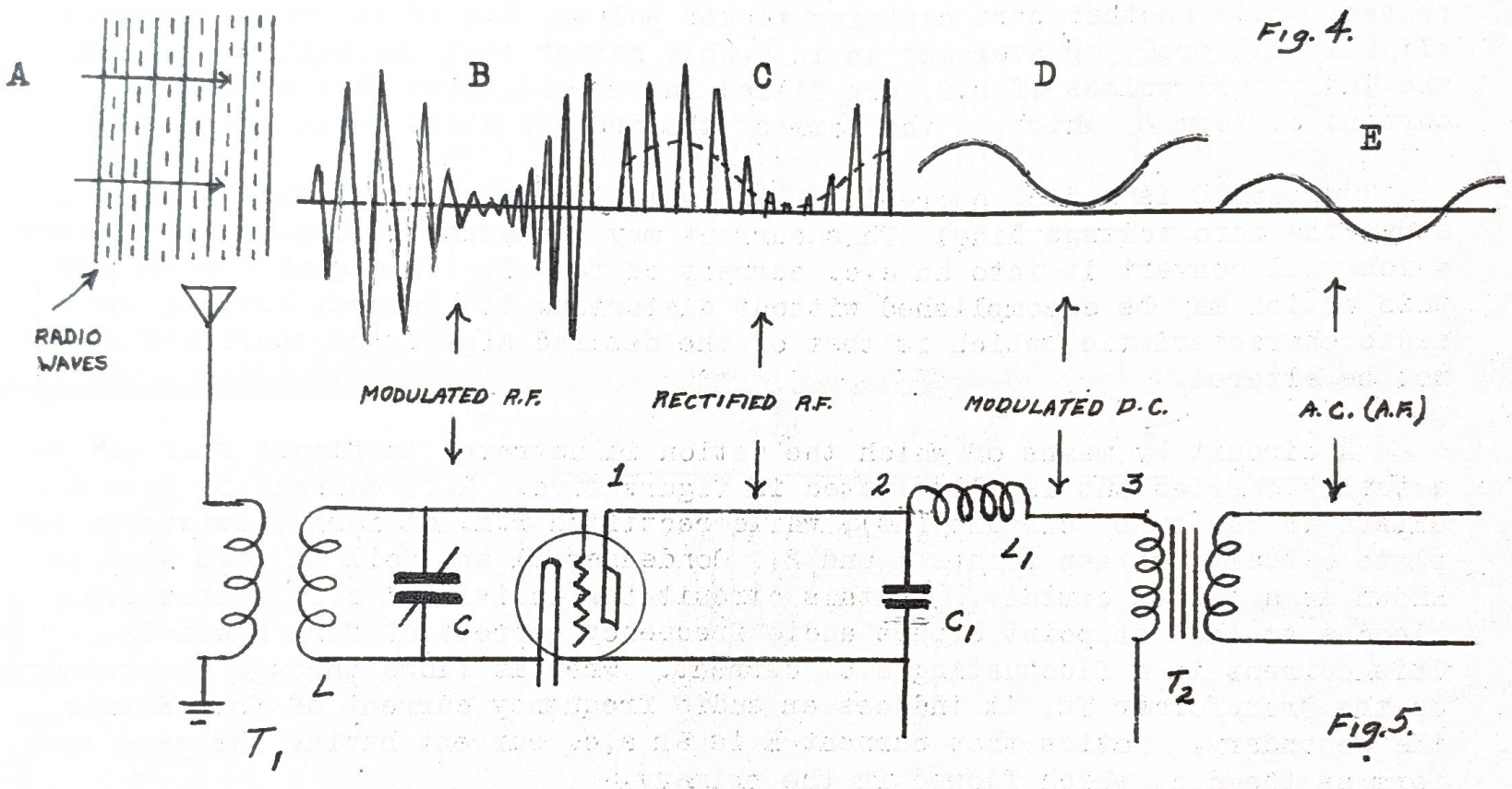


Fig. 5.

THE DETECTOR

When the various tubes of the radio frequency amplifier are properly adjusted, they each will increase the intensity of the radio frequency signal, but will in no wise distort or alter the modulation pattern of the r.f. signal from the form which it was given by the modulator tube of the transmitter. We find that an r.f. signal will reach the detector stage of a good receiver carrying exactly the same outline that it had when it commenced its journey. The purpose of the detector in a radio receiver, is to transform this outline into an actual audio frequency current.

To serve as a detector, a radio frequency tube must be operated in a very special manner which we will not go in to here. For the moment it is only necessary to know that when operating as a detector, a tube no longer amplifies the radio frequency signal, but instead, acts to produce an audio

frequency current having the form of the modulation pattern. The actions taking place in the detector stage are illustrated in figure four. In figure four, A is the radio wave, B is the r.f. current induced into the antenna, and as it appears when amplified by the various r.f. amplifying tubes of the receiver. This current swings above and below the centre line in positive and negative half cycles. Because it is an alternating current, its average value will be zero. At C we have another kind of radio frequency current. Here all the half cycles which extended below the straight line at B, have been cut away and only the half cycles above the line remain. As the half cycles extending below the line were negative, and the half cycles above the line were positive, we find that the r.f. current now consists of a series of positive half cycles only. This type of current is known as a "rectified r.f. current". Its average value will bo longer be zero, but actually will represent the desired audio signal. One part of the rectified r.f. signal contains strong pulses, while another part contains weaker pulses, and if the whole thing is slightly filtered, or averaged up in such a manner that the hollows between the individual pulses of r.f. are filled in, we will find that we have a current of form D, which is the form of the desired audio frequency signal.

Current D is a d.c. current, as is indicated by the fact that it is all above the zero voltage line. This current may be passed through a transformer which will convert it into an a.c. current of form E. In a good transformer this action may be accomplished without distorting its general outline, or audio characteristic, which is that of the desired signal and therefore must not be altered.

A circuit by means of which the action illustrated in figure four may be actually carried out is illustrated in figure five. R.f. current of form B exists in the tuned circuit (LC), while rectified r.f. of form C exists in the plate circuit between points 1 and 2. Condenser C1 and coil L1 form what is known as a filter circuit. In this circuit the individual r.f. pulses are blended so that at point 3 pure audio frequency current of form D exists. This current is a fluctuating d.c. current. When it flows through the primary of the transformer T2, it induces an audio frequency current of form E into the secondary. Notice that current E is an a.c. current having the same wave form as the d.c. which flowed in the primary.

THE AUDIO FREQUENCY SECTION

The audio frequency current output of the detector is usually not very strong and is insufficient to operate a loudspeaker satisfactorily. For this reason one or two stages of audio frequency amplification usually follow the detector tube of every set. Audio frequency amplifying stages may be coupled by means of a transformer, as illustrated in figure six, or by means of special resistance coupling such as is illustrated in figure seven. In figure six the audio output of the detector is fed to the primary of transformer T1. This transformer may have a step up ratio between primary and secondary, and in this manner an audio voltage actually higher than that produced by the detector may be fed to the grid of the first audio amplifying tube. The strength of the audio frequency signal is further amplified in tube 2 and is led on to a second transformer. If amplifying tube 2 is the only one employed between the detector and the speaker, then transformer T2 will be a coupling transformer employed to match the impedance of the speaker to the plate

resistance of the amplifying tube. In this case no voltage gaain will be possible in the transformer, and the power applied to the speaker will be only the power output of amplifying tube 2.

Resistance coupling between audio amplifying stages, such as is illustrated in figure seven, has come into widespread use of recent years. It has certain advantages over transformer coupling, even though voltage gain is not possible with it. Audio voltage is conveyed from one stage to the next by means of coupling condenser C. Resistance coupling is never used between the output tube and the speaker, as conditions at that point are very different to conditions existing between two audio amplifying tubes.

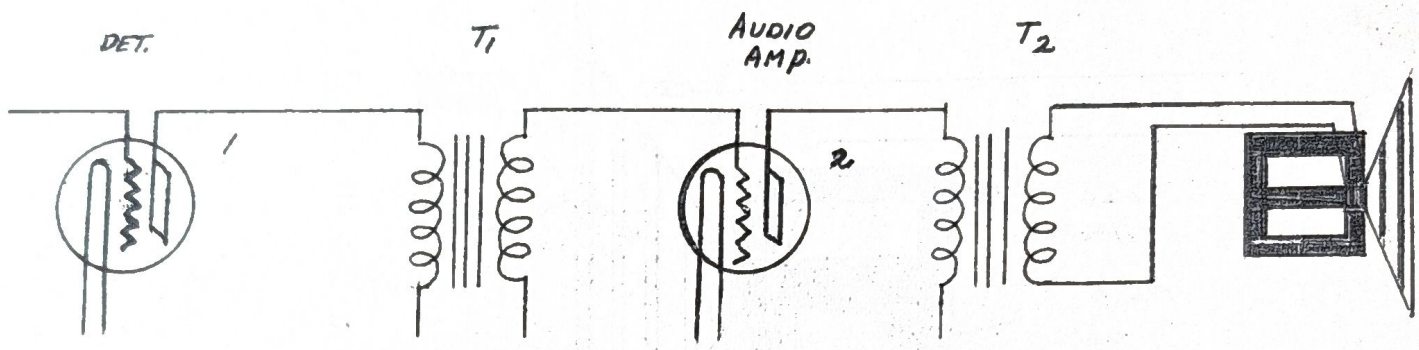


Fig. 6.

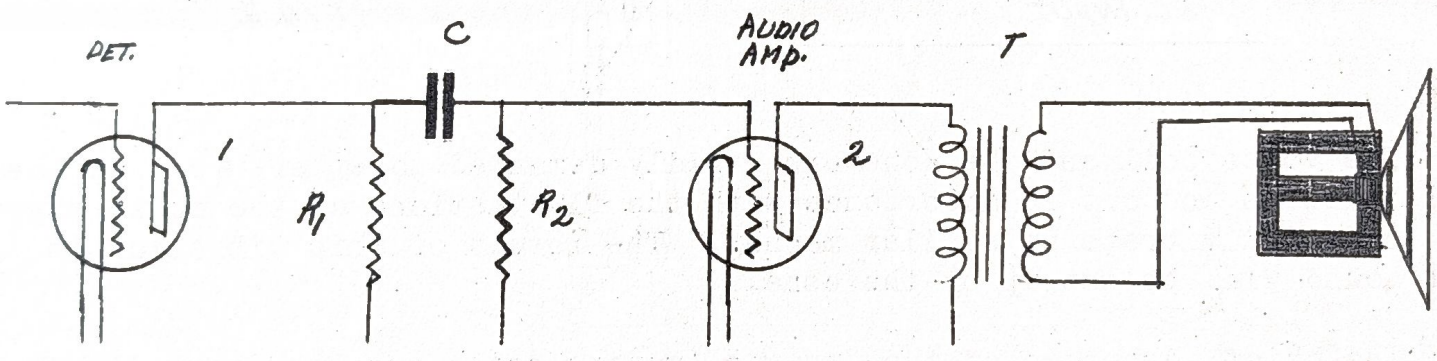


Fig. 7.

THE SPEAKER

The purpose of the loudspeaker of a radio set is to produce sound, when fed with audio frequency current. In a radio receiving set, audio frequency current originates in the detector. It is amplified by one or more stages of audio frequency amplification and is passed on to the speaker. The speaker is thus the last link in our chain from sound in the broadcast studio, the to the reproduction of sound in the home. The loudspeaker is a very vital link in this chain, for it must reproduce sounds that are recognizable, and which otherwise are satisfactory to the listener.

The loudspeaker illustrated in figure eight, is known as a dynamic speaker. It consists of three principal parts; A vibrating cone which is the actual sound reproducing mechanism, a voice coil attached to the apex of this cone and floating in a magnetic field, and a strong field magnet. The field magnet in this speaker is an electromagnet energized by d.c. current flowing through a field coil which consists of many hundreds of turns of fine wire. This

electromagnet produces a very strong magnetic field across the air-gap in which the voice coil floats. The audio frequency current developed in the secondary of transformer T2, of figure six or seven, flows through the voice coil of the dynamic speaker. Current through the voice coil sets up a magnetic field which will be in opposition to the field produced by the field magnet. This action will cause the voice coil to push outward, away from the field magnet, in the direction of the arrow. Because the voice coil is energized with audio frequency current, which is, of course, a current of fluctuating intensity, the repelling force of the voice coil will vary. At one moment the current will be strong and the coil will push outward to a considerable extent. At the next instant the current in the voice coil may be low and the voice coil will drop back.

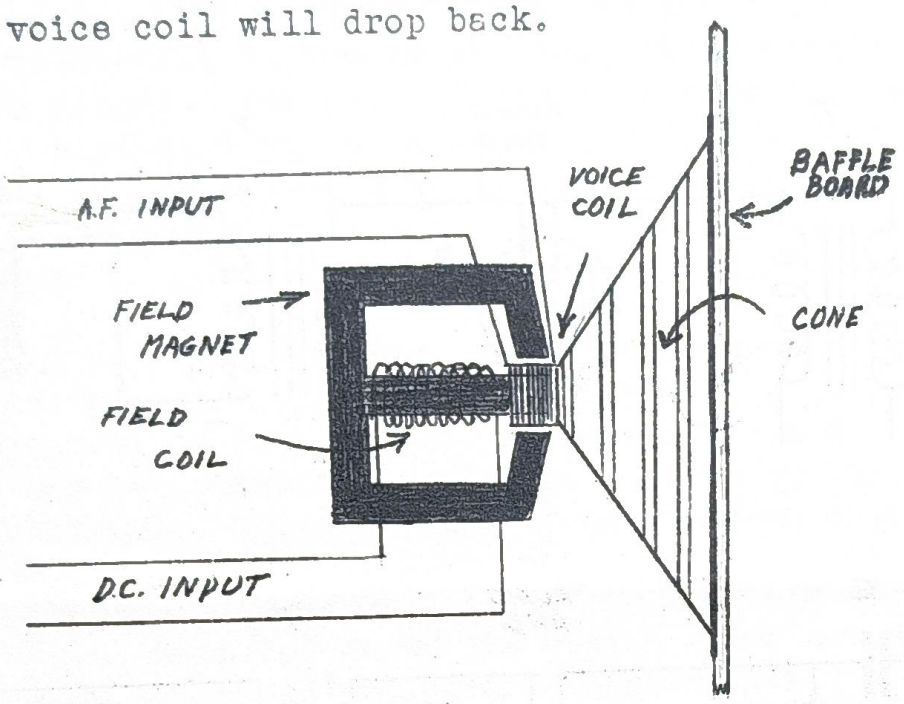


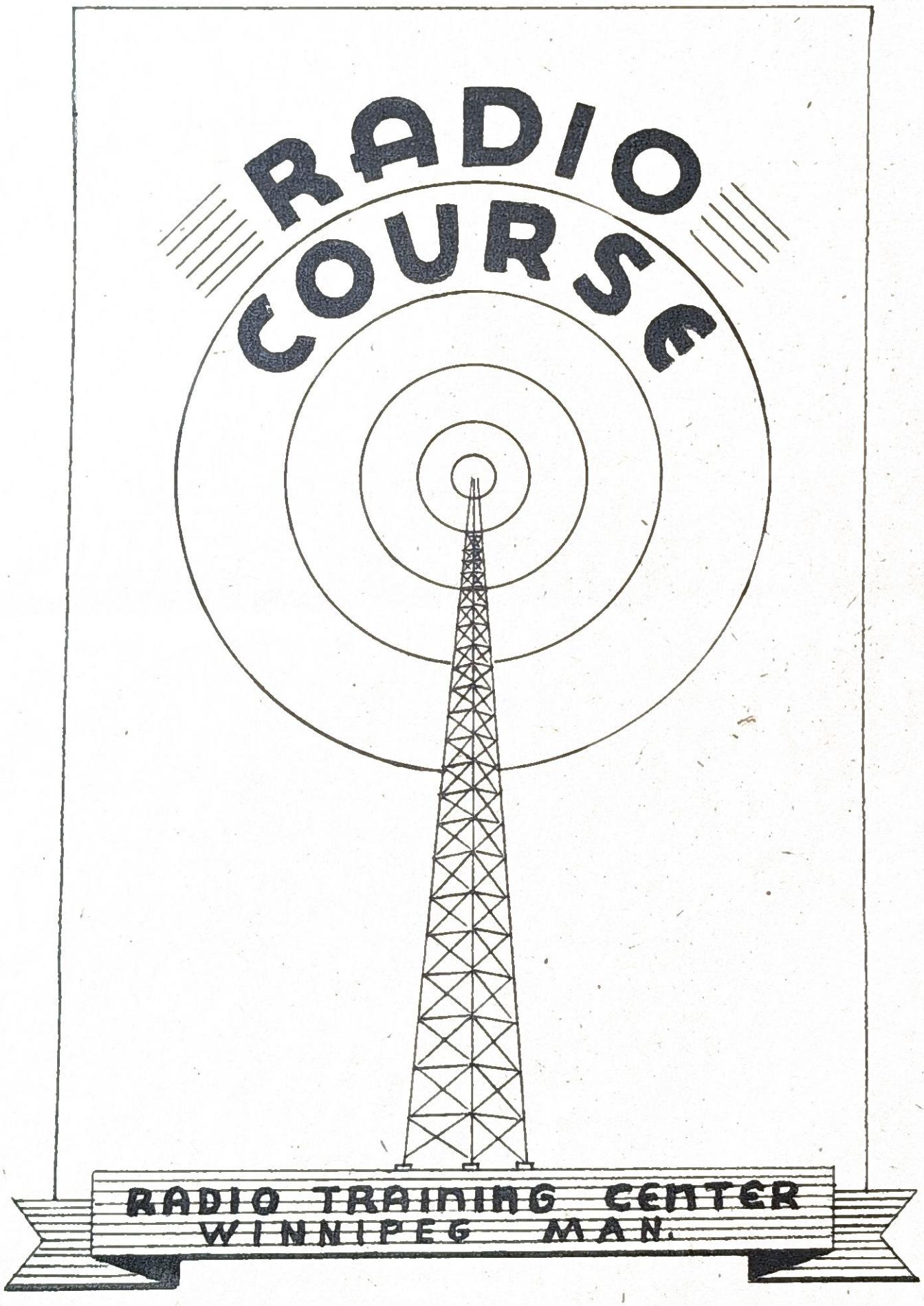
Fig. 8.

The voice coil and the cone are rigidly cemented together, and, as the coil moves in and out in accordance with the fluctuations of the audio signal the cone will vibrate in similar manner. The result of this vibration is that sound will be set up by the cone.

The chief advantage of the dynamic (moving coil) speaker over all others is that the voice coil is free to move back and forth over a very wide range, which permits the speaker to reproduce loud sounds without distortion.

TEST QUESTIONS

1. How is the field magnet of the speaker illustrated in figure 8, energized?
2. What are the two purposes of the r.f. amplifiersection of the receiver?
3. What two types of current are combined to produce modulation in the circuit of figure two?
4. What kind of current flows in the grid circuit of a detector tube?
5. What are the two types of coupling for use between audio amplifying stages?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LESSON SIX

ELECTROMAGNETIC WAVES

As every one must realize, if they stop to consider the matter at all, in order a radio program may be "picked up" by a home receiver, some physical connection must exist between the broadcasting station and the receiver. The connection which exists is entirely invisible and consists of electro-magnetic waves, popularly termed "radio waves", which radiate in all directions from the antenna of the broadcasting station. These radio waves rush outward into space at terrific speed, and can be made to traverse immense distances. Radio waves have been known to pass completely around the world, arriving back at the starting point a fraction of a second after leaving. They are capable of reaching almost anywhere, and will pass through almost anything.

Radio has been described as the most astonishing of modern inventions. But radio waves are not the invention of man, they are a natural occurrence, only recently discovered and made use of.

WAVE MOTION

Before we consider the nature of radio waves, we must have a working knowledge of wave motion and the terms which apply to this type of motion.

If a length of rope, or heavy cord, is attached at one end to some solid object and stretched taut in the hand, a brisk to and fro motion of the free end will result in a ripple forming and running the length of the rope, poss-ibly reversing at the fixed end, and returning to the hand. This action is a good example of wave motion. The ripple which ran the length of the cord is a wave. A series of waves (a wave train) may be produced by moving the free end of the cord briskly from side to side. Irregular or single waves, such as were formed in the first example, do not occur in radio. All radio waves intentionally transmitted, and practically all natural waves, occur in rather lengthy groups.

Figure one is a diagram of a series of waves following a regular pattern. These may be electrical waves, or they may be simple waves in a cord. Each individual wave, it will be noticed, is substantially the same in size and shape as the ones immediately preceding and following. We say "substantially the same" because even in the case of radio waves, minute differences do exist, especially when the signal is modulated. The difference between ad-jacent wave crests, in the case of radio waves, however, is usually impossible to detect. The wave pattern shown is the standard form utilized to illustrate electrical and radio wave motion. A diagram of this type is referred to as a "sine wave", though we cannot go into the explanation of this term at the present.

In figure one, the portion of the diagram lying between points 1 and 2 is referred to as a "cycle of wave motion". This is because the sine wave, changing all the way from point 1 to 2, commences at point 2 to repeat it-self and, between points 2 and 4, passes through a track identical to that which it has just traversed between points 1 and 2. The space between points 1 and 2, 2 and 4, 4 and 5, or the space between any two adjacent points which are in the same phase, is termed a "wave length". Understand what is me ant by points in the same phase. Points 1 and 2 are in the same phase. Similarly

points 6 and 7, and points 8 and 9, are in the same phase when considered with respect to one another. Pick any two points on the sine wave between points 1 and 2. Then pick the corresponding point on the sine wave between 2 and 4. The two will be in the same phase, and will be one wave length apart. Thus it will be seen that the wave length of a signal is simply the length of one complete cycle of wave motion. For reasons which will be explained shortly, the wave length of a signal varies with the frequency of wave motion.

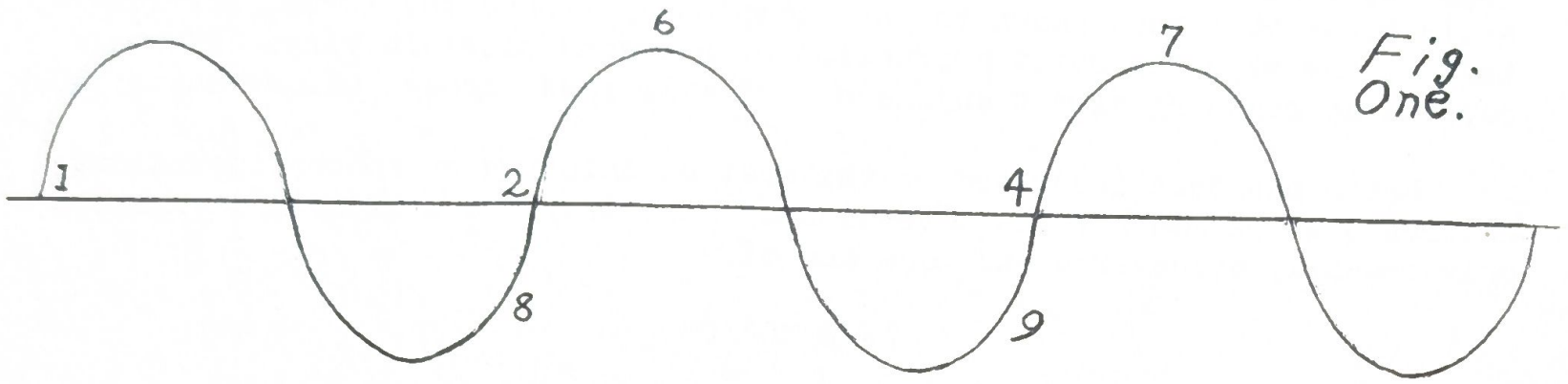


Fig. One.

The term "frequency of wave motion", or as it is usually expressed, "signal frequency", is a term indicating the number of cycles of wave motion completed in a second. A one-thousand cycle signal would thus be a train of waves, the individual waves of which recur at a frequency of one thousand per second. The term will be better understood if we consider it this way: All waves are produced at a source, and they rush away from this source at a definite speed. Point your finger up into the air and imagine radio waves (in the form illustrated in figure one), rushing by. Because these waves are passing at a definite speed, it is easy to grasp the idea that a definite n number of waves will pass your finger each second. Thus the term "frequency of wave motion" means the number of complete waves, or cycles, which will pass any given point in one second, and this figure is expressed by stating that the signal consists of so many cycles per second.

THE ELECTROMAGNETIC SPECTRUM

Electromagnetic waves can be produced at all frequencies above 10,000 c.p.s., and the full spectrum of electromagnetic waves is quite interesting to comtemplate. In it are light waves, ultra-violet rays, infra-red rays and radio waves. The relationship which these waves bear to each other is illustrated graphically in Figure two. It will be noticed that one group of waves differs from another group only because the frequencies of the two groups are different. Yet in actuality, each group of waves shown has amazingly different properties, and each will react in an entirely different manner under any given set of conditions.

In the electromagnetic spectrum, radio waves occupy the lowest frequency bands. All of the others are at higher frequencies, while some are at exceedingly high frequencies. In this study we will be interested chiefly in radio waves, though quite a bit will also be learned about light rays and the other rays mentioned.

Electromagnetic waves are often referred to as radiations, due to the fact that they radiate from a source. In the case of radio waves, the source of radiation is the antenna of a broadcast station.

FREQUENCY AND WAVE LENGTH

In practical work, the student may often wish to determine the wave length of a transmission of known frequency, or, again, to determine the frequency of a transmission of known wave length. Three factors enter into this calculation, and these are, velocity, frequency, and wave length. If two of these factors are known, the third may always be computed. But as the velocity of radio wave motion is a constant, to determine either the frequency or the wave length of a transmission it is only necessary to know the value of one of these, and to remember the constant, velocity. The velocity of radio waves is 186,000 miles per second, but as radio wave lengths are invariably measured in terms of the metric system, and not in terms of the English land measure (miles, yards, feet, etc.), the velocity of radio waves must be had in meters. This figure is 300,000, 000 meters, or 300,000 kilometers per second. Moveover, in radio work, the frequencies considered are often quite high. The standard broadcast band, for instance, extends from

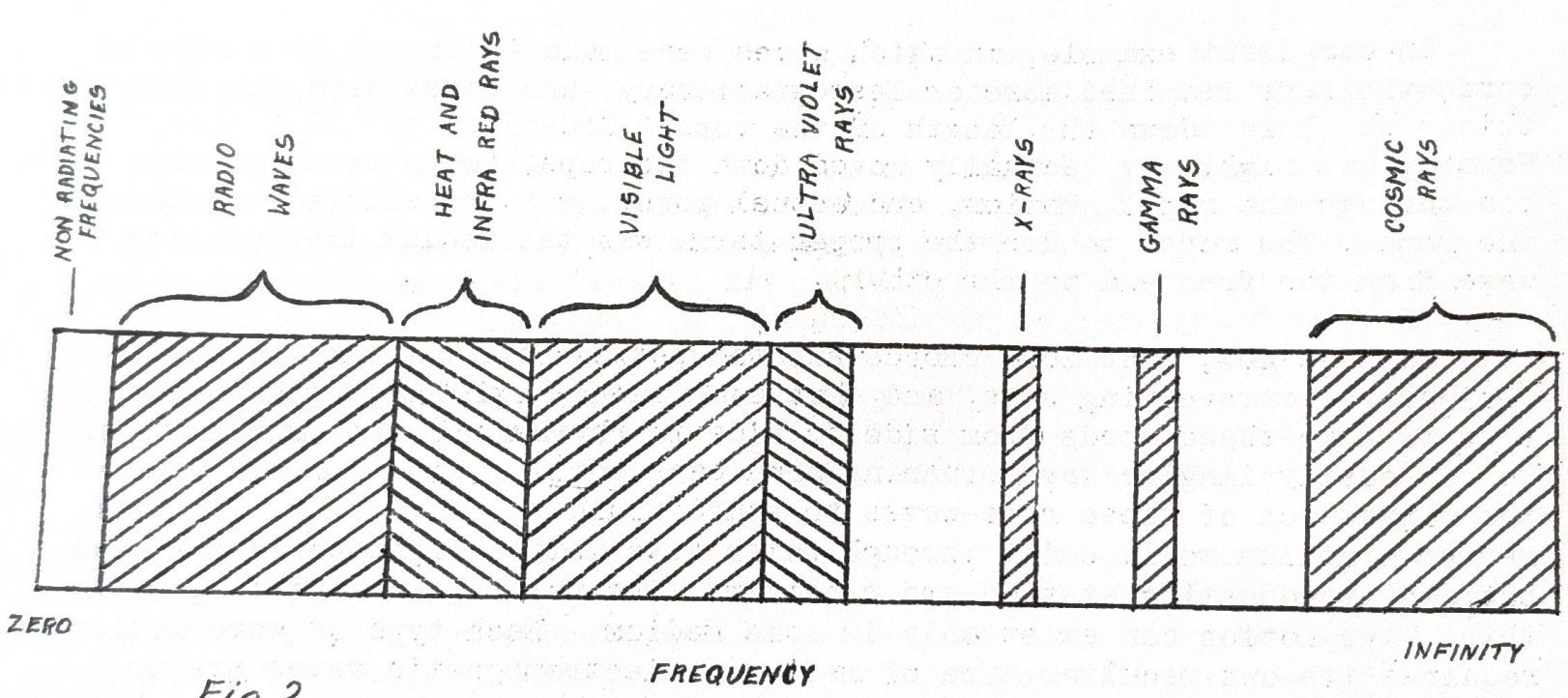


Fig. 2.

500,000 to 1,500,000 cycles per second. As a convenience, these figures are usually reduced by making use of a term known as a "kilocycle". A kilocycle (k.c.) is a thousand cycles, and the standard broadcast band, in terms of kilocycles, extends from 500 kc. to 1,500 k.c. In practical radio work, frequencies are almost always measured in kilocycles, so you must remember this term.

But to return to our calculations for frequency and wave length. The constant figure, (velocity, i.e. 300,000 k.m.) divided by frequency, will give us the wave length of a transmitted signal. In making such calculations it must always be remembered that if velocity is in meters, frequency will

be in cycles, and it is only when velocity is in terms of kilometers, that frequency will be in kilocycles. To find the wave length of a 1,000,000 cycle broadcast, for instance, velocity (in meters) would be divided by frequency in this manner:

$$\frac{300{,}000{,}000 \text{ meters}}{1{,}000{,}000 \text{ cycles}} = 300 \text{ meters}$$

But as it is more simple to write:

$$\frac{300{,}000 \text{ k.m.}}{1{,}000 \text{ k.c.}} = 300 \text{ meters}$$

we find that the latter form is the one most often used.

Frequency of a broadcast may be determined by dividing velocity by wave length. Here too, velocity must be in terms of kilometers, if frequency is to be in kilocycles.

For practical use the following formulas should be kept in mind:

$$\frac{300{,}000}{\text{Frequency (in k.c.'s)}} = \text{wave length.} \qquad \frac{300{,}000}{\text{Wave length}} = \text{frequency (in k.c.'s)}$$

THE WAVE MEDIUM

In our first example, in which waves were made to travel in a rope or cord, the rope remained more or less stationary, and waves were the only things which ran down the length of the rope. Consider this idea carefully. Nothing, we might say, actually moved down the rope, yet a wave, or ripple, ran through the rope. Motion, and actual power, was transmitted by means of the rope. The rope, to use the proper term, was the medium transmitting the wave from the free end to the other.

Suppose now, that long chords existed between a radio station and the various radio receiving sets, and that some agency existed at the radio station to flip these cords from side to side in rhythmical wave-like motion. We can easily imagine waves running down each cord to the receiver, though the conversion of these rope-waves to sound would be impossible. In this manner a medium would exist through which wave motion might be transmitted between broadcasting station and receiver. The point we are getting at is this: Wave motion can exist only in some medium. Each type of wave motion requires its own peculiar type of medium. Electromagnetic waves are no exception to this rule, and they, too, must have a medium through which to travel.

Because it is quite certain that wave motion does travel between the radio transmitter and the receiver, it is obvious that some medium must exist through which these waves may flow. But what can this medium be? Every type of wave motion, we said, requires a special type of medium for its transmission. Waves of a certain type travel in water. Sound waves travel through the air, water, and more or less well through numerous other substances. Sound waves will not travel through a vacuum (an area devoid of known substance such as the space remaining in a tank when all air has been removed). But radio waves will traverse a vacuum, and for this reason they would seem to require no medium for their transmission. But because this fact is contrary

to all known laws of wave motion, it is assumed that radio waves do require a medium for their transmission, but this medium, which is presumed to exist, has not yet been isolated and identified.

This unknown medium through which electromagnetic waves travel, is referred to as "ether", and it is assumed to permeate all space, both intermolecular and interstellar. It is everywhere. A school boy once defined ether as the "something which is left when everything is removed", and his definition comes very close to the truth. Ether should not be considered as a gas, for it has definitely no gaseous properties. Much more likely it will prove to be associated in some manner or other with electricity.

But, no matter, we know that electromagnetic radiations are set up by radio stations, and that these radiations consist of waves transmitted through the unknown medium, ether. These waves traverse the intervening space at the speed of light (300,000 k.m. per second) and arrive at the receiving antenna. It is at this point that our study of radio really commences.

RADIO WAVES AT THE RECEIVING ANTENNA

Although sounds are produced in the studio, and similar sounds are produced in the home receiver, sound waves do not traverse the intervening space. Radio waves, consisting of electromagnetic vibrations, are transmitted, and not actual sound waves.

Nor do radio waves rush down the antenna to enter the home receiver. The only thing that flows in the receiving antenna is an electric current, and this current is set up by the action of passing electromagnetic waves, transmitted from a radio station. The second property of an electromagnetic wave, then, is its ability to induce an electric current into a wire. The action taking place at the receiving antenna is similar to the action taking place when moving magnetic flux is used to induce current into a wire, as was illustrated in an example given in lesson 3. It is because of this marked similarity to the magnetic flux surrounding a simple magnet, that these waves have been given the name "electromagnetic waves".

RADIO FREQUENCY AND AUDIO FREQUENCY CURRENTS

The electromagnetic waves which are radiated from a transmitter are beyond the range of audibility. Vibrations recognizable as sound extend all the way from a very few vibrations, or cycles per second, up to about 10,000 or 20,000 per second, but radio waves, to radiate at all, must be of high frequency. The lowest frequency radio signals which will actually radiate are just at the peak of audibility (about 10,000 cycles per second), but in this case exceedingly long antennas are required. From this point they extend up to hundreds of millions of cycles per second. The lower group of frequencies, which are within the audio range, are referred to as audio frequencies (a.f.) while the frequencies at which ether radiation takes place, are referred to as radio frequencies (r.f.).

RADIO FREQUENCY AS A CARRIER OF AUDIO FREQUENCY

Radio waves, being of a frequency greatly above the audio range, induce into the antenna of a home receiver an alternating current of a frequency

above audibility. Even though this r.f. current is not of audible frequency it can be used as the carrier of audio frequen cy signals. This is done in the following manner: The radio frequency current induced into the receiver antenna by the passing electromagnetic waves, is not of constant intensity. It is an alternating current swinging up and down at radio frequency, and its amplitude will be found to vary with the intensity of the a.f. signal originating in the radio studio. The variations in intensity of the r.f. signal may be isolated in the receiver, by a process known as "detection", to give rise to an audio frequency current of the same pattern as the original produced at the studio.

MODULATION

At the transmitter a high frequency (r.f.) current is set up having a constant intensity. If this signal were fed directly to the antenna, a series of radio waves would be transmitted, but no a.f. signal would be produced at the receiver. Such a transmission is termed an "unmodulated transmission", and of course, occurs normally only when the station announcer ceases talking for an sinstant. If an a.f. current is now produced at the transmitter, and if the over-all intensity of the radiated r.f. signal is caused to vary in accordance with the momentary intensity of this a.f. current, then the r.f. wave which reaches the receiving antenna will no longer be of constant intensity, but will be modulated in the pattern of the a.f. signal. The process of impressing the a.f. current upon the r.f. radiation is known as "modulation".

DETECTION OF THE AUDIO FREQUENCY SIGNAL

The current induced into the antenna of a home receiver by passing radio waves, varies in intensity with the variations in amplitude of the passing waves, and will thus carry all of the modulations contained in the transmitted signal. But these modulations must be converted to an electric current if they are to be understood. This conversion process is known as "detection", as it is at this point in the receiver that an audio frequency signal is first discovered, or detected. A special tube is employed in all receivers to serve the purpose of detector of the a.f. current. This tube is termed the detector. Various types of detectors will be considered in the following lessons.

Figure three is a block diagram depicting the course of a radio signal in its journey from the broadcast studio to the home receiving set. It contains, in one diagram, all of the processes which we have just considered.

At the upper left, sound waves produced in the studio strike the diaphragm of the microphone. A vibration is set up in the diaphragm, and this produces a modulated current in the microphone. This current then flows into the audio amplifier, where the a.f. current is amplified before passing to the modulator. An r.f. current of constant intensity flows in to the modulator from the oscillator on the left. In the modulator the a.f. signal current is impressed upon the r.f. current. This process is known as "modulation". The modulated r.f. is then passed on to the r.f. amplifier where it is increased to a high strength before being fed to the antenna. The r.f. current surging up and down in the antenna, sets up a series of electromagnetic waves which radiate in all directions from the antenna.

At the right is shown the home receiver. The electromagnetic waves rushing by, induce into the receiving antenna an r.f. current similar to the current which previously flowed in the broadcast antenna. This induced vurrent flows into the r.f. amplifier where it is greatly increased in strength before being passed on to the detector. In the detector, the r.f. current is rectified and an a.f. current produced of similar pattern to the a.f. current which existed at the modulator stage of the transmitter. The a.f. current is next amplified in the audio amplifier, and is finally fed to the speaker. At the speaker sound waves are set up of a similar nature to the sounds which were produced in the broadcast studio.

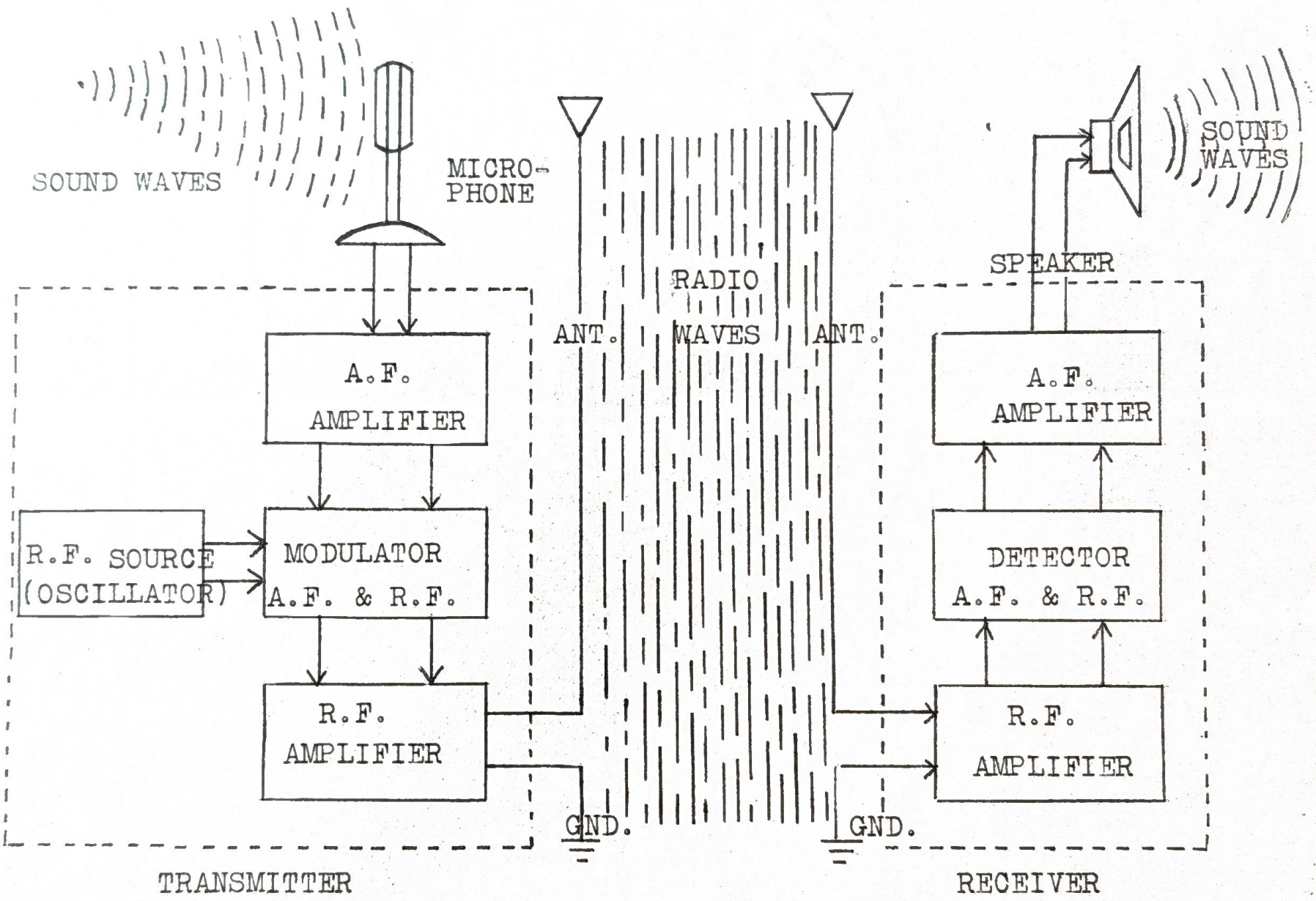
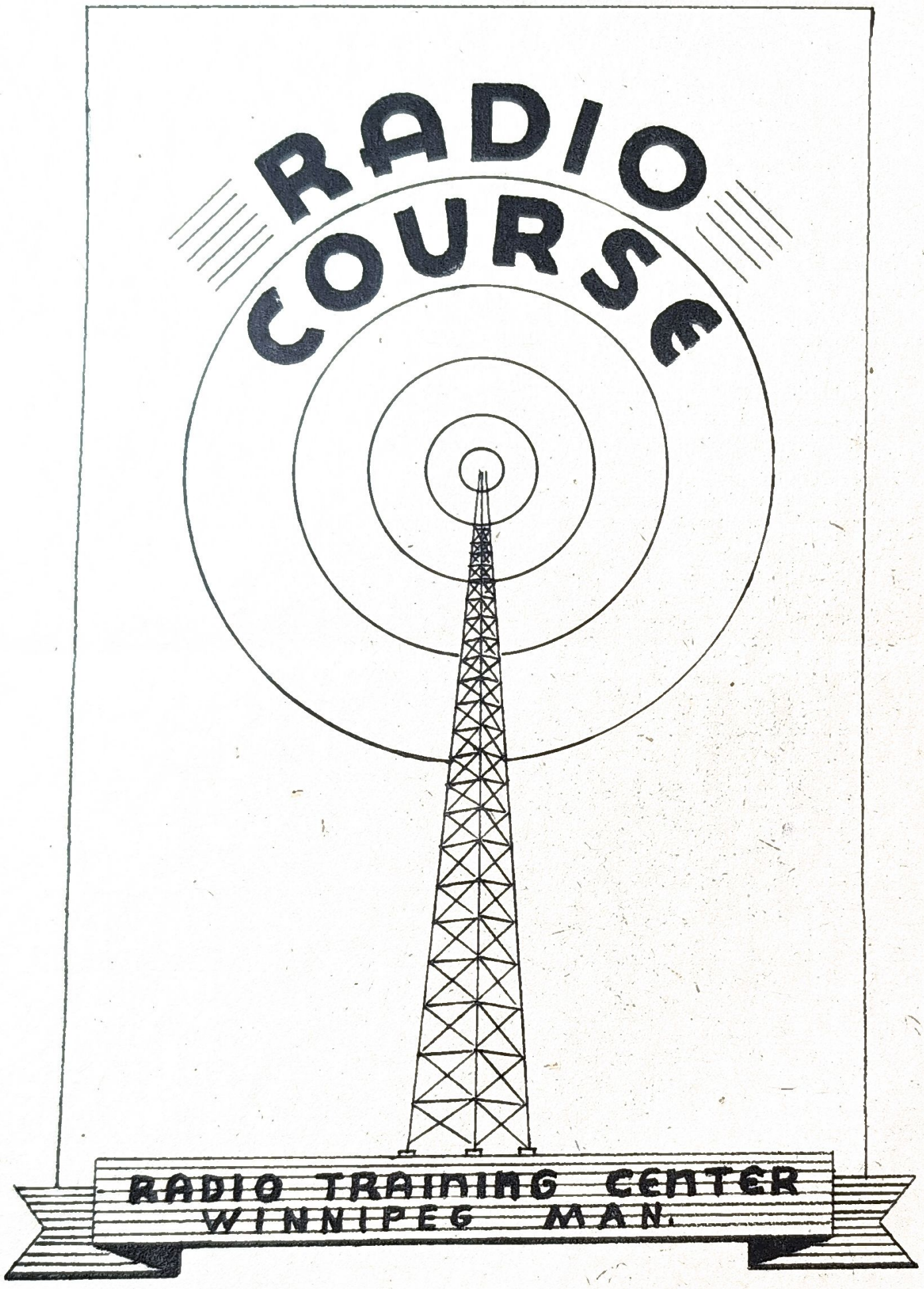


FIGURE THREE

TEST QUESTIONS

1. Through what medium do sound waves usually travel to reach the ear?
2. Through what medium do radio waves travel?
3. Give the names of three electromagnetic radiations.
4. What is the wave length of a radio signal of 400 k.c.?
5. What is the frequency of a radio signal having a wave length of 80 meters?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LESSON SEVEN

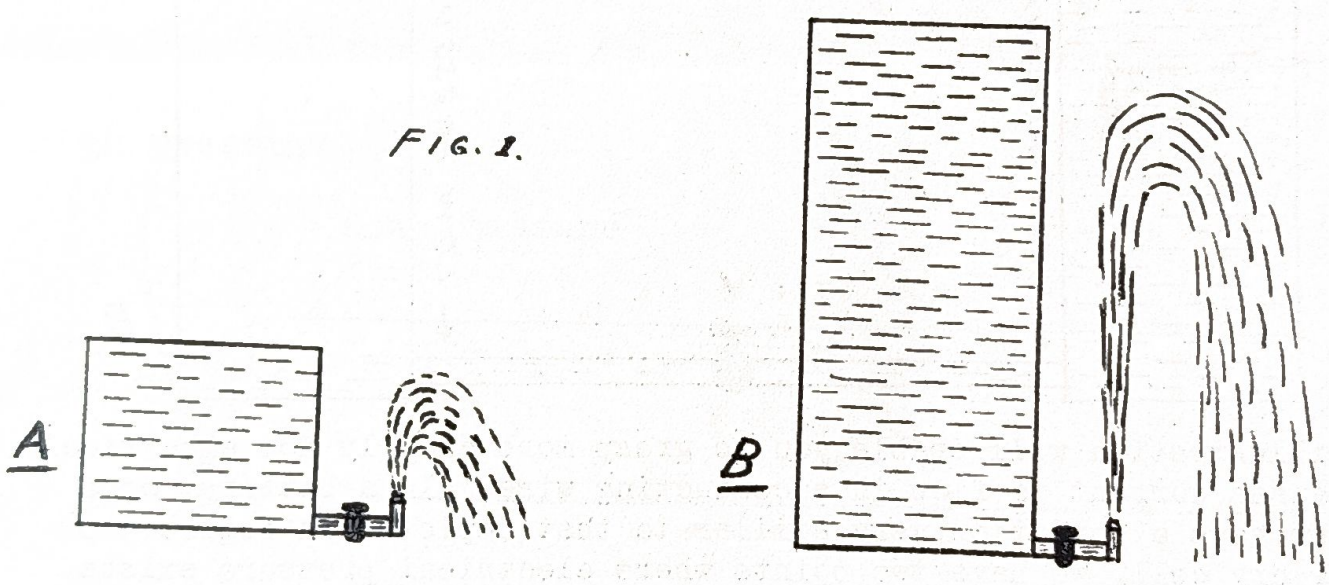
FACTORS GOVERNING CURRENT FLOW

As has already been pointed out, when considering a flow of electricity, there are three main things which must be considered. These are, PRESSURE CURRENT, and RESISTANCE. As these occur in every electrical circuit, we must set aside this lesson to learn all that we possibly can about these factors, and how to perform certain simple mathematical calculations with them.

In this lesson we are going to use a water analogy to illustrate electrical pressure and its effect upon current flow. Let us suppose that we have a tank ten feet deep, such as tank A in figure one. At the bottom of this tank, considerable pressure will exist. When the valve in the upturned pipe at the bottom of the tank is opened, the pressure in the tank will cause a jet of water to be thrown into the air. This jet is shown in figure one.

At B we have another tank. This tank is 30 feet high, or three times as high as tank A. It is also full of water, and it too causes a jet of water to be thrown into the air from the upturned pipe at its bottom. Notice that this tank will throw a jet of water three times as high as the jet thrown by tank A. Why is this? Because the water in tank B is three times as deep as the water in tank A. It develops three times as much pressure at its bottom, and this increased pressure is responsible for the appearance of the larger jet.

FIG. 1.



The foregoing will help us to understand electrical pressure, or voltage. The pressure of the water at the jets in figure one may be compared to the electrical pressure which exists at the terminals of a battery or mechanical generator. Since the pressure at the bottom of tank B is three times as great as the pressure at the bottom of tank A, three times as much water per minute will emerge from tank B, and the jet will be three times as high. Similarly with electricity. When pressure is increased, current flow will increase. If other things are equal, when the electrical pressure applied to a circuit is increased three times, then three times as much current will flow in the circuit. Or, if electrical pressure is increased four times, then four times as much current will flow, and so on.

ELECTRIC PRESSURE — VOLTAGE

As you know, if a complete conducting path is provided to connect two points between which a difference of electrical pressure exists, a flow of current will take place in the conducting wire. The strength of this current will depend partly upon the amount of electrical pressure exerted, and this will be the difference of pressure which exists between the two points. To illustrate this point let us refer again to our tanks of water. Supposing the tanks are connected together by a pipe containing a valve, as shown in the assembly illustrated in figure two. The height of water in the first tank, tank K, is 30 feet, while the height of water in tank L is only 10 feet. Obviously greater pressure will exist at the bottom of tank K than exists at the bottom of tank L. As long as the valve V is closed, no water will flow through the pipe, but when the valve is open, what will happen? Water will flow from tank K into tank L. There is a difference of pressure between the bottoms of the two tanks, and water flows through in an effort to equalize this difference. Note carefully that there is pressure at the bottom of both tanks, but that the pressure at the bottom of tank K is greater than the pressure at the bottom of tank L.

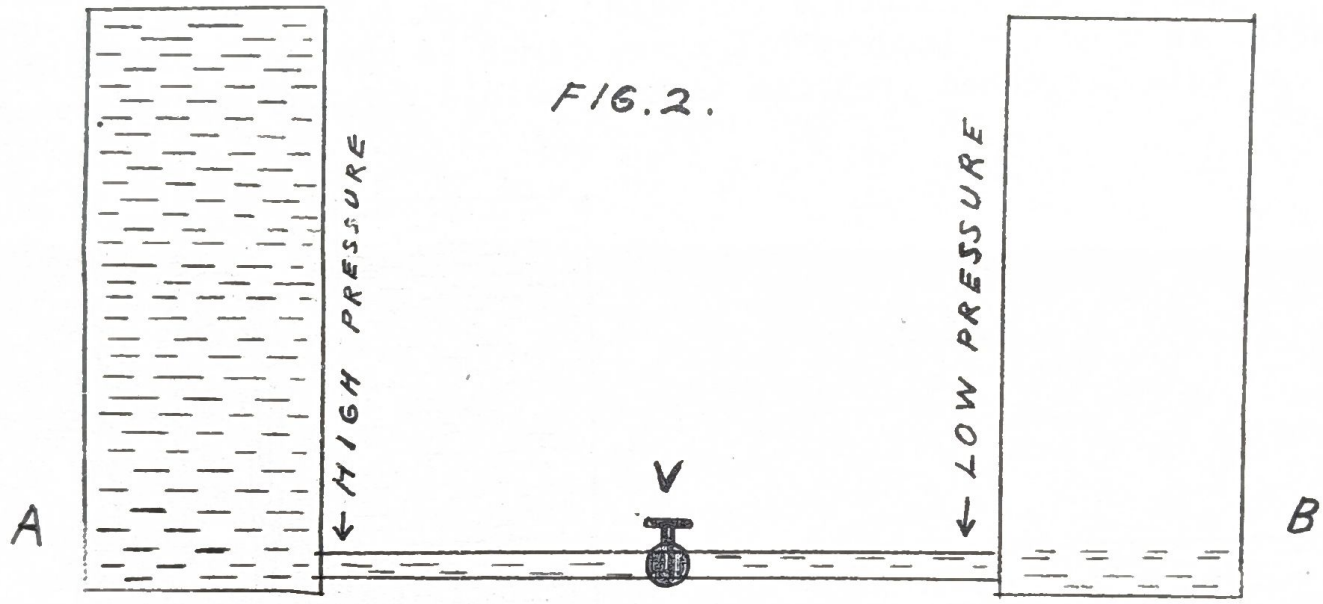


FIG. 2.

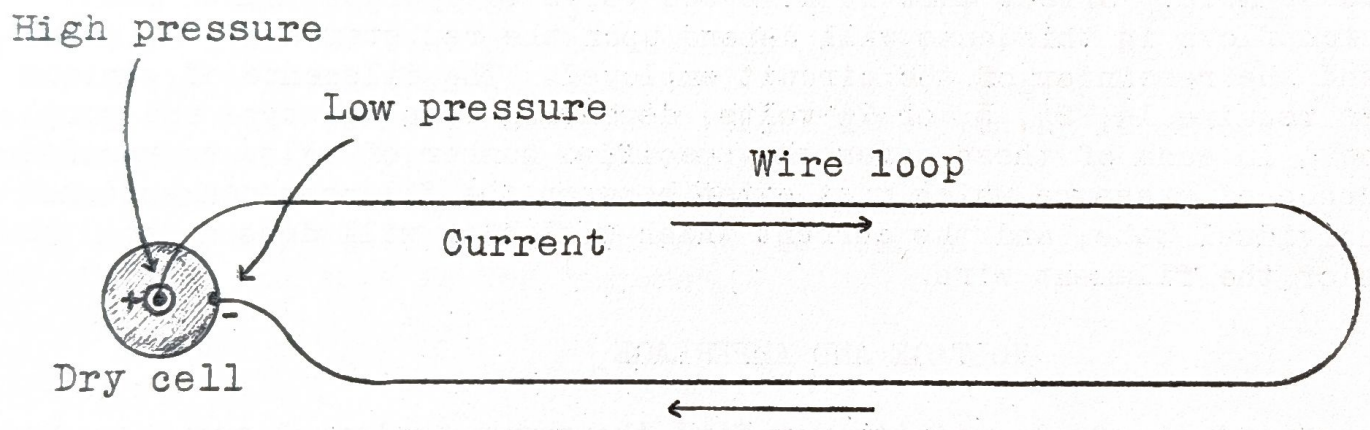
This illustration will enable you to grasp more clearly how electrical pressure causes current to flow in a conducting wire. In a battery, or a dry cell, we have a condition very similar to that depicted in figure two. In a single dry cell, we have two points where electrical pressure exists. These are known as the terminals. One terminal has high electrical pressure while the pressure at the other is quite low. Normally no current flow takes place between the two because there is no conducting path connecting them. The condition is exactly like the condition existing when valve B is closed in figure two. A flow of water does not then take place because the connecting circuit is not complete. In figure three we have the electrical equivalent of figure two. A single dry cell is shown with its terminals connected by a long loop of wire. Electrical pressure exists at the cell terminals. At the positive (+) terminal this is quite high and tends to force a current of electricity out at that terminal, through the wire loop, and back into the cell at the negative (-) terminal. This current flow tends to equalize the difference of pressure existing between the two terminals, just as the flow of water between the tanks in figure two tends to equalize the pressure difference existing at the bottom of the tanks. In the case of the dry cell,

however, a great deal of electricity may flow between the terminals before the pressure will actually become equalized. This is because pressure is built up constantly by chemical action in the cell. If tank K in figure two was a large reservoir constantly replenished by rainfall, we would have a very similar set-up to that existing in a simple dry cell in which electrical pressure is maintained at a constant level throughout the life of the cell.

It is electrical pressure which causes electric current to flow. The unit of electrical pressure is the "volt", and consequently the electrical pressure acting in a circuit is usually spoken of as the "voltage" of the circuit.

We must always remember that the terms "steam pressure", "air pressure" "water pressure" and even "electrical pressure" really imply that a difference of pressure exists between two points. It is the difference in pressure between two points in an electric circuit that is referred to as the "voltage" of the circuit. This might also be spoken of as the "voltage drop", the "potential difference", or even the drop in "potential" between the two points. This will be clear when you recall that the difference in height between two points of a stream of water, for instance the top and bottom of a dam, is spoken of as the "difference in level", the "drop in level", or simply as the "drop" between these two points. And, just as the difference in water level will produce a flow of water if the proper circuit of pipes is installed, a difference of electrical potential, or voltage, between two points, will produce a flow of electricity when a suitable conducting circuit is connected between the points where the difference in electrical pressure exists.

Figure Three.



Another name for electrical pressure, or voltage, is "electromotive force". Sometimes instead of writing in the whole word electromotive force, only the three letters e.m.f. are used. So when you see the abbreviation e.m.f. you will know that it means exactly the same thing as voltage or electrical pressure.

ELECTRIC CURRENT

The next thing we must consider is the current flow which will take place when voltage is applied to a circuit.

We must have electrical pressure or voltage in a circuit before an electric current will be set up. The rate at which water will flow through a

pipe, as we have already learned, depends to a very great extent on the pressure, or driving force, behind it. This water pressure is measured in pounds per square inch, and the rate of flow in gallons per minute.

Electrical pressure, on the other hand, is measured in volts, and electrical current in amperes. The number of amperes of electric current that will flow in a wire will depend in part on the voltage which is applied to the circuit.

You understand that higher water pressure will be needed in order to force a given amount of water through a small pipe than would be required if the pipe were of larger diameter. So, in the case of an electrical circuit, we will not be surprised to learn that higher electrical pressure will be required if we wish to force a given amount of electricity through a small wire than would be needed if the circuit consisted of a larger wire of the same material. A smaller pipe offers greater resistance to the passage of water, and, consequently, greater pressure is required to force water through it than would be the case if resistance were less. A small wire, in the case of an electrical circuit, has greater resistance than a large wire of the same material, and for this reason a higher voltage will be needed to force an electric current of any given value through it than would be the case if the wire were larger and of less resistance.

When you use the starter in your car the electrical pressure utilized is six volts, furnished by the storage battery in the car. Owing to the fact that the starter motor has very large diameter wires, the resistance is not very great. Hence a large amount of electricity flows, which may amount to 100 amperes or more. Street cars require 500 volts to operate them. The current which flows in this case will depend upon the resistance of the motor windings and the remainder of the circuit employed. The filaments of various radio tubes require $1\frac{1}{2}$, $2\frac{1}{2}$, 5, or $7\frac{1}{2}$ volts, depending upon the type and purpose of the tube. In each of these cases the specified number of volts represents the difference of pressure which must exist between the filament connections to each individual tube, and the current which will flow will depend upon the resistance of the filament wire.

VOLTAGE AND AMPEREAGE

The new student of electricity may find the terms "voltage" and "ampereage" as applied to the workings of various circuits, slightly confusing, and he may wonder just what is a "volt" and what is an "ampere". A perfect understanding of these terms must be had if progress is to be made in electrical work, so we will take time right here to acquire this knowledge.

A "volt" is a unit of electrical pressure, while an "ampere" is a unit of current flow. As the student probably knows, it is possible to have high voltage and yet no current (or ampereage) whatsoever in a circuit. The circuit of figure five A will depict this condition. The circuit shown contains a break or gap across which current does not flow even though voltage is maintained across the gap. And it is possible, also, to have varyingamounts of current, or amperage, in a circuit even though the voltage applied to the circuit is constant. In figure four we have drawn two tanks. Let us suppose that each is ten feet high. Each tank is equipped with an outlet at the bottom, fitted with a valve, by means of which the pipe may be opened or

closed. The pipe leading out of tank A is quite small, say about a quarter of an inch in diameter, while the pipe leading out of tank B is quite large, being perhaps as much as 5 inches in diameter. As both tanks are of the same height, they will develop the same pressure at the bottoms. But when the valves are open, which tank do you think will empty itself first? Tank B of course? Clearly more water will flow out of tank B during each second than will flow out of tank A. This is the point we want to consider. Even though the pressure is the same in both tanks (at starting, that is) a much larger stream of water will flow from tank B than will flow from tankA.

Pressure at bottom of both tanks equal

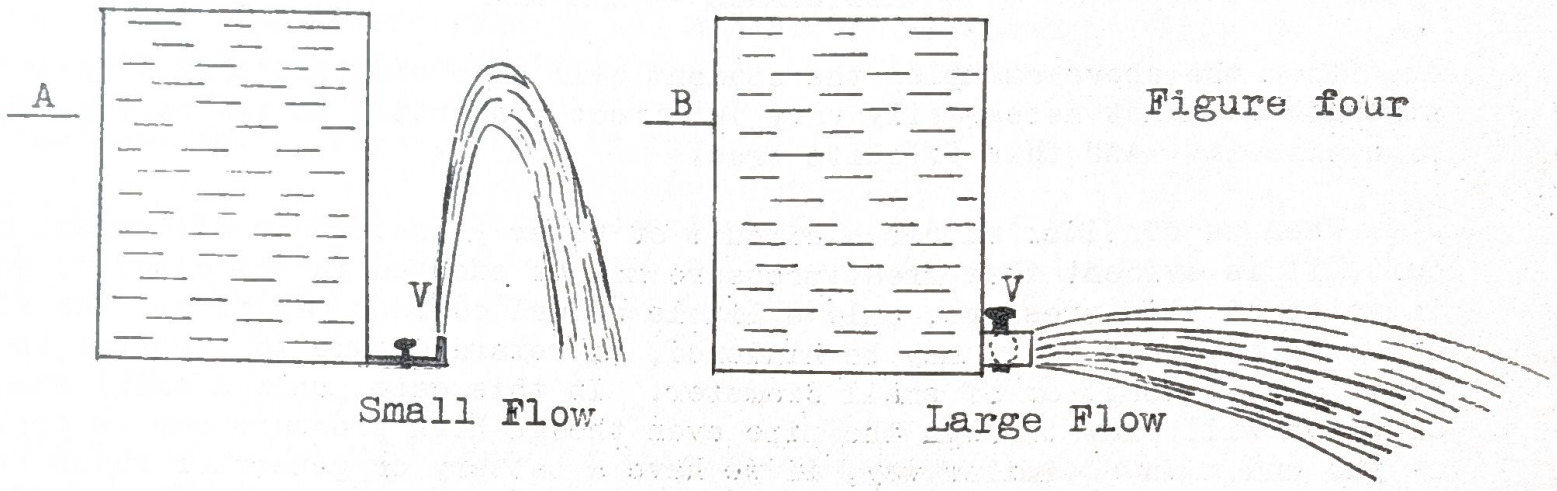
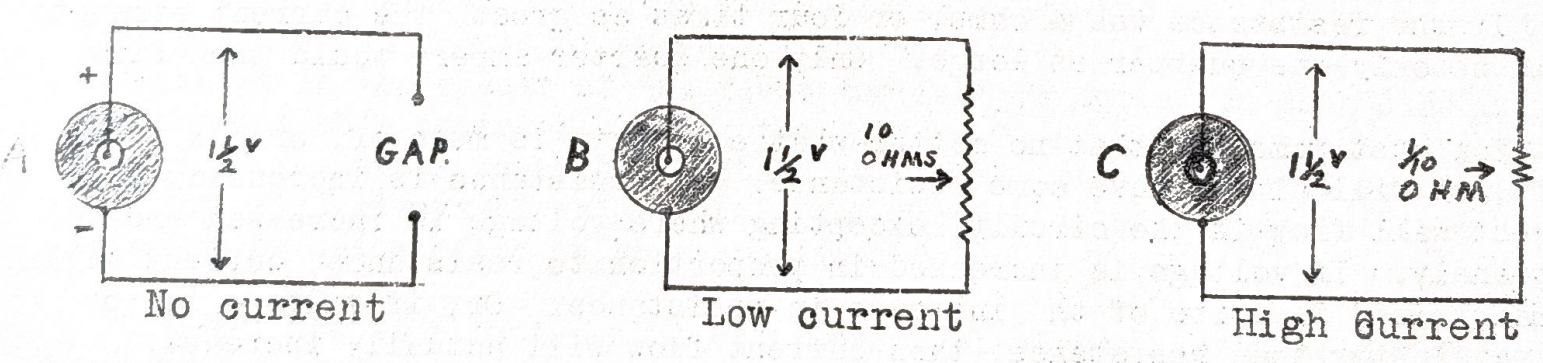


Figure four

The amount, or volume, of water emerging from these tanks during each second, does not depend upon pressure alone. The other factor responsible will be considered shortly. For the present we want to clearly establish one fact and this that the amount of electricity flowing past a point in an electrical circuit is a variable factor, just as the amount of water flowing from a tank is variable with the size of the opening. Electricity flowing past a point in a circuit is spoken of as "current", and the amount of this flow is referred to as the "current strength". Where this flow is large, current is considered to be heavy. Where flow is small, current also is small, or light. In water circuits there is no unit for use in measuring the flow of water, other than to say "gallons per minute". But in electrical circuits we have a unit of flow, and this is the "ampere".

Figure Five



An ampere thus is a unit for use in measuring the amount of electricity flowing through a circuit during each second of time. A 10 ampere current is a current consisting of 10 amperes per second, and is, of course, ten times greater than a current of only 1 ampere.

The distinction, then, between voltage and apereage is this: The term "Voltage" indicates the pressure which drives current through a circuit, while ampereage is a unit used to measure the current itself. The voltage of a circuit may be high while the ampereage is low, or again, amperage may be high while voltage is low. A high-voltage power transmission line is a good example of the first possibility. In it current flow is comparatively low although the voltage driving the current along the wires is often exceedingly high. On the other hand, in the case of an electric welding outfit, the applied voltage is usually very low, being only about 5 to 20 volts, while current strength often is exceedingly high.

RESISTANCE -- THE OHM

From the above examples the student will have realized that current strength does not necessarily vary in direct proportion to the voltage applied to a circuit. And this is quite true.

When we consider either a circuit of water pipes, or an electrical circuit, it is evident that great pressure may be exerted in the circuit, yet, in spite of this pressure, only a little actual current may flow. The flow of water in a pipe circuit may be hindered, or retarded, due to the fact that the pipe is very long, or of small diameter. In this case, only a small amount of water will flow through the pipe even though high pressure may be applied at the end. In a similar way, if we have a battery or generator which produces a very high electrical pressure, or voltage, and if this pressure is applied to a circuit consisting of a wire of very small diameter, and of considerable length, only a very small amount of electricity will flow in the circuit. From this it will be seen that whether we are dealing with water, or with electricity, there is something in addition to pressure that will affect the amount of current which will flow in the circuit. This something is RESISTANCE.

Resistance is a property of every wire, though in some cases it is quite small. Resistance acts to hinder the passage of electric current, and so tends to limit current flow. Consequently, a large voltage will be needed to force current through a wire having high resistance.

The unit of electrical resistance is the "ohm". A wire has a resistance of 1 ohm when a pressure of 1 volt will force a current of 1 ampere through it. If the resistance was 4 ohms, or four times as great, the current strength would be only one quarter as large. Only one quarter ampere would then flow.

You must remember that no matter what a circuit is made of, or how it is built, it will always have some resistance. If resistance is increasedm kess current will flow in the circuit, excepting where voltage is increased proportionaly. If voltage is increased in proportion to resistance, current will be maintained in spite of th increase in resistance. Or, if voltage is increased faster than resistance, then current flow will actually increase. We can make a general statement to cover these facts, and this is that current strength will vary in direct proportion to changes in voltage (i.e. the two will go up and down together), where resistance remains constant. And second that current will vary in inverse proportion to resistance which means that current will vary in the opposite manner to a variation in resistance. If

resistance goes up, current will go down, or, if resistance goes down, then current will go up. The word "inversely" means opposite to (just as to invert means to turn over). So when things are said to vary in inverse proportion, it means that the two vary opposite to each other, yet to the same extent, When it is stated that current varies in inverse proportion to resistance, it simply means that current rises when resistance falls, but that the increase in current will be exactly proportional to the reduction of resistance.

OHMS LAW

The facts which we have just enumerated were first discovered by the distinguished scientist George Simon Ohm. He developed a law covering the matter, and it was later named in his honor. It is known as Ohm's Law. As this law is possibly the most important of all electrical laws, we will restate it once more. It states simply that current varies in direct proportion to voltage, and that current varies in inverse proportion to resistance.

Ohm's law, when put into mathematical form, states that current in an electric circuit will always be equal to the quotient of pressure divided by resistance. This may be expressed as follows:

$$\text{CURRENT} = \frac{\text{PRESSURE}}{\text{RESISTANCE}} \qquad \text{or} \qquad \text{AMPERES} = \frac{\text{VOLTS}}{\text{OHMS}}$$

But instead of using full words in this formula we may substitute symbols such as the following:

I instead of current (derived from the word "Intensity".)
E instead of pressure, or Volts (derived from Electromotive Force.)
R instead of resistance.

By using only symbols Ohm's law may be expressed in mathematical form as follows:

$$I = \frac{E}{R} \qquad \text{OR} \qquad \frac{E}{R} = I$$

There are different methods of remembering Ohm's Law, but the one which the writer would suggest is this: In the equation above, where it is stated that $\frac{E}{R} = I$ it should be remembered the first thing you need to have before current will flow in an electric circuit is electromotive force or voltage. The second factor is Resistance (R), which is an unavoidable part of any circuit. This is placed under the E. Resistance opposes current flow and therefore governs the amount of current which will flow. Current (I) comes last, because it is the result of the first two factors acting on each other. Remembering this order of placing the factors E, R, I, and remembering that E goes above, and R beneath, and that the two in this form will equal current (I), you will always be able to call the formula to mind when you need it, and this may be quite often in your practical radio work.

Ohm's Law is a fundamental equation of electrical science, and forms the foundation of nearly all electrical calculations. Therefore we must give this law a great deal of careful study.

We will next learn how to use Ohm's Law in simple arithmetical calculations. Don't get the idea that we are going to burden you with a whole lot

of arithmetic or mathematical problems, because that is not our intention. In several following lessons, as well as in your practical radio work, you will be called upon to multiply and divide and perform simple mathematical problems. If your knowledge of simple arithmetic is not great, or if you feel a little rusty on this work, we suggest that you acquire an intermediate school text book on arithmetic and brush up a bit in your spare time. Time spent in this manner will not be wasted.

All problems dealing with Ohm's Law areworked out by replacing the words, current, voltage and resistance, or their abbreviations, I, E, R, with the actual values of these factors in numbers. To perform calculations utilizing the formula for Ohm's Law given above, it will always be necessary that you know the values of two of the factors before you can find the third. That is to say, it would not be possible for you to find both resistance and voltage when you know only the value of current strength, excepting where you are equipped with meters, but that is a different situation. For the moment we are considering only actual mathematical calculations.

If you have studied fractions you will know that if $I = \frac{E}{R}$ then $R = \frac{E}{I}$ and $E = I \times R$. We shall prove the truth of the foregoing by letting $I = 4$, $E = 12$, and $R = 3$. Then taking the Ohm's Law formula, $I = \frac{E}{R}$ and substituting numbers for the symbols we will have $4 = \frac{12}{3}$. As 12 divided by 3 does equal 4, we see that this is true. We said $R = \frac{E}{I}$. Let us see if this is also true. By substituting numbers in place of letters we obtain $3 = \frac{12}{4}$, and as 12 divided by 4 equals 3, we see that it also is correct. Now taking the last form of Ohm's Law which says $E = I \times R$, and by substituting the proper values in place of the letters, we find that $12 = 4 \times 3$, which is also correct.

Let us next test our knowledge of this law with a few practical applications.

Problem 1. How much current will flow through a lamp which has 25 ohms resistance, when a pressure of 110 volts is applied to its terminals?

Solution. We will make use of the formula $I = \frac{E}{R}$. We have learned that in the formula I stands for intensity of current in amperes, E stands for Electromotive force in Volts, and R stands for Resistance expressed in Ohms. Of the three symbols in the formula, we know the value of only two, E and R, so our problem will be to determine the value of I. Taking the formula $I = \frac{E}{R}$ and substituting the two values which are supplied, we discover that $I = \frac{110}{25}$. Dividing 25 into 110, we find that I is equal to 4.4 amperes.

Problem 2. What voltage will produce a current of 12 amperes in a circuit having a resistance of 36 ohms?

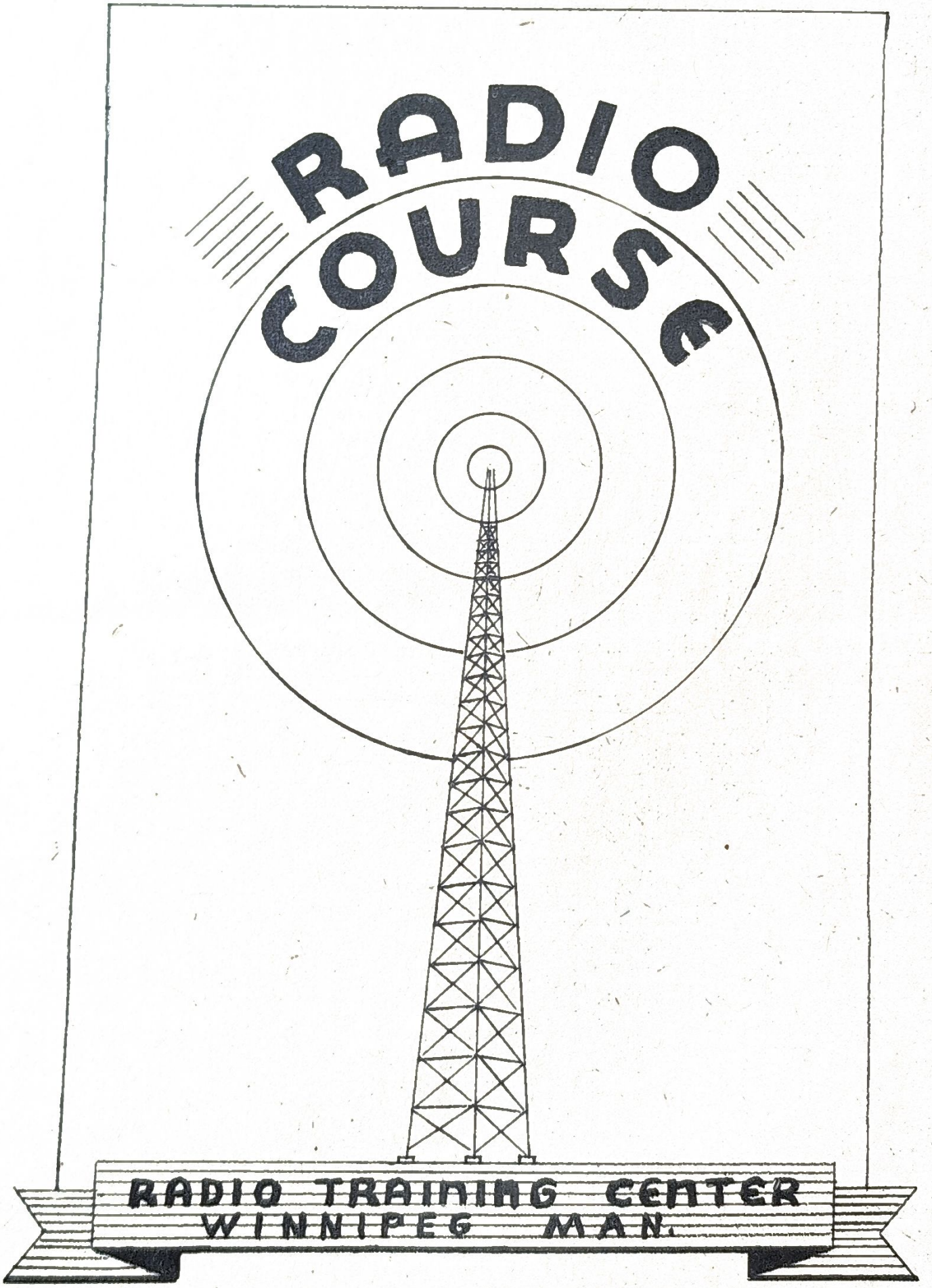
Solution. This time we take the formula $E = I \times R$ and by substituting we learn that $E = 12 \times 36$ which is equal to 432. Therefore E = 432 volts.

Problem 3. Through what resistance will 90 volts force 18 amperes of current?

Solution. Here we have to find the resistance of a circuit, so this time we use the equation $R = \frac{E}{I}$. Substituting the known values for E and I, we find that $R = \frac{90}{18}$. As $\frac{90}{18} = 5$, we discover that the resistance of the circuit will be 5 ohms.

TEST QUESTIONS

1. In electrical calculations to find the value of electromotive force, we multiply current in amperes by what?
2. What current will flow through a 6 volt light bulb which has a resistance of 30 ohms?
3. Explain what the abbreviation e.m.f. stands for.
4. If the resistance of a circuit remains constant, what will happen to current strength when voltage is doubled?
5. Find the current strength when voltage is 10 and resistance 5 ohms.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LESSON EIGHT

~~LESSON SIX~~

MAGNETIC CIRCUITS

We are going to study magnetism in this lesson. The former lessons dealt with electricity and electrical laws, but since many parts of a radio receiver depend upon magnetism for their efficient operation, it will be necessary for us to study magnetic laws, and learn all that we can about their application to radio circuits. Transformers, choke coils and speakers could not work if it were not for magnetism. No doubt you have heard about permanent magnet dynamic speakers. Later on in the course you are going to learn how magnetism is utilized in these and other radio speakers to reproduce speech and music. When you reach these lessons you will understand why magnetism is such an important subject. For this reason we trust you will make a special effor t to master all of the principles outlined in this lesson.

WHAT THE ANCIENT GREEKS LEARNED ABOUT MAGNETS

The Ancient Greeks discovered that there is one form of stone which possessed the strange property of attracting bits of metal such as iron. They also learned that by rubbing bits of iron with this stone, the iron would automatically become endowed with the same strange power of attracting pieces of iron, and would behave in exactly the same way as the magnetic stone. By a little experimenting these early scientists discovered that when one of these stones was suspended from the end of a string it would always turn and point in a North and South direction. It was discovered that this type of stone invariably exhibited this property. Practical use was soon made of these stones. They were used to "lead" people, or guide them when traveling and they soon became indispensable to people who travelled through localities where they might get lost. In this manner the stones came to be called "leading stones" or lodestones.

Hunters and sailors soon started using these stones to find their directions. Out of this practical use evolved the modern compass, which is in reality nothing more than a magnetized needle placed on a pivot which allows it to swing freely and so place itself in a North and South direction.

TEMPORARY AND PERMANENT MAGNETS

There are two classes of magnets, namely, temporary and permanent magnets. It was discovered long ago that the metals iron and steel are very strongly affected when brought into contact with a magnet, while other substances are not noticeably affected. For this reason iron and steel came to be called magnetic substances. A magnetic substance is a metal which a magnet will attract.

Natural magnets, or "lodestones", are found in nature in the form of stones. In addition to these natural magnets we have what are called artificial magnets. An artificial magnet is one that is made by man. It was early discovered that when steel is rubbed against a lodestone magnet, and specially treated, it will itself become a powerful magnet. A magnet of this type is called an artificial magnet. When steel is properly magnetized, it will retain its magnetism almost indefinitely. Consequently, steel magnets are usually permanent magnets. Iron, too, becomes magnetized when placed

close to a magnet. But when the magnet is removed the iron loses its magnetism. We call a magnet of this type a temporary magnet. You must remember these two terms: TEMPORARY MAGNETS and PERMANENT MAGNETS. You will learn a little later on that both these types of magnets are utilized extensively in radio and electrical work.

MAGNETIC POLARITY

If a bar magnet is suspended from the end of a string, it will always turn and point in a North and South direction. We may explain this action by saying that the earth itself is a huge magnet and that its field causes the small magnet to line up in this manner. You must remember that one end of the bar magnet will always point South and the other North. We call the end which always faces North, the North seeking pole, and the end that faces South, the South seeking pole. For the sake of brevity the poles are usually marked simply "N" & "S" at the ends. The "N" pole is the one that faces North while the "S" pole is the one that faces South. You will learn in your studies that it is at the extremities of a bar or horseshoe magnet that the attracting power is strongest. This is the reason why we refer to the ends of a magnet as its "poles".

If you haveever had occasion to experiment with small magnets, no doubt you will have noticed how a pin or needle will actually jump towards a magnet when brought within a quarter of an inch of it. From this experiment it would seem obvious that some form of power must extend out into the space surrounding a magnet. This is true, and the area over which power extends is referred to as the "magnetic field of force", a field comprised of invisible "magnetic lines of force". These lines radiate from the ends of a magnet and form the magnetic field. When the two poles (North and South) are close to each other, as in the case of a horseshoe magnet, the space between the two poles will be magnetically charged. We call this area a space of "Magnetic Stress" because it is in this field that magnetic attraction will be most pronounced.

THE MAGNETIC FIELD

Let us look for a moment at Figure one. Here an ordinary bar magnet is illustrated showing how it would look if the magnetic lines of force were visible to the eye.

You will notice that these lines start at one pole and pass through the air in a large loop reaching back to the other pole. Each magnetic line of force forms a complete circuit. These lines flow from the North pole, through the air to the South pole, then through the magnet back to the North pole. A great many of these lines of force are contained in the magnetic field. The speed at which these magnetic lines travel is the same as that of light or electricity, namely, 186,000 miles per second.

In considering magnetic actions we will never be concerned with the work performed by an individual magnetic line of force. Usually we must take all of the lines in a magnetic field and consider them as one group. Magnetic lines of force when considered together are spoken of as "magnetic flux". The term "magnetic flux" thus includes all of the magnetic lines in a magnetic circuit.

As you already know, a magnetic circuit is a complete path traversed by lines of force travelling from the North pole of a magnet through the air to the South pole and then through the magnet back to the North pole. Magnetic lines travel in circles, more or less, and this is the reason why some authorities say that magnetism may be a form of electricity in rotation. No one definitely knows what magnetism is. Just as in the case of electricity, we endeavour to study the effects of magnetism and to put them to practical use. We can do no more than speculate on the essential magnetic force in our attempt to learn why magnets behave the way they do. The principal purpose of scientific investigation, however, is to learn to make use of the effects rather than to delve too deeply into the cause of natural phenomena.

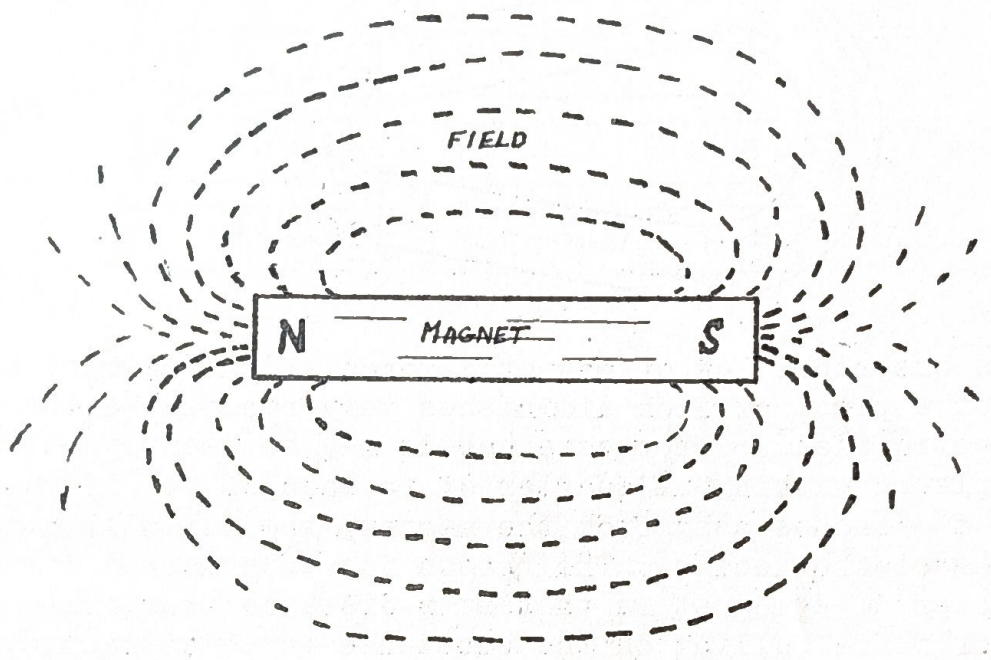


Figure 1

TWO FUNDAMENTAL LAWS OF MAGNETISM

There are two fundamental laws of magnetism that you must learn. If you were to suspend two magnets from the ends of a string and hold them in the air so as to have them swing freely in any direction, you would notice that when the north seeking poles come together the two magnets would be pushed away from each other and would not come in contact. You would also observe that when two south poles come close to one another they too would tend to fly apart. In other words, the south seeking pole of one magnet would push away from, or repel, the south seeking pole of the other magnet. The north poles will repel each other in a similar manner. But when two unlike poles, such as the south pole of one magnet and the north pole of another magnet come close together, the poles will attract each other and they will draw together. The same thing will happen when the north pole of our first magnet is brought close to the south pole of the other magnet.

From this we conclude that unlike poles of a magnet attract each other, while like poles repel each other. This is a fundamental law of magnetism and you must make certain that you remember it always.

In your studies later on you may have an opportunity to see how magnetic lines of force behave when you bring different poles together. You may even see these lines in action if you sprinkle iron filings on a piece of glass

and place a magnet under it. The filings will arrange themselves in definite patterns conforming to the magnetic lines of force.

You must think of each magnetic line of force as forming a complete circuit. Unlike electricity there is no way in which magnetic lines may be insulated or their flow prevented. There is no substance that is capable of stopping these lines entirely, for they will pass through anything. Originating at the North pole, these lines flow out into the air, circle around towards their own South pole where they re-enter the magnet and pass through it back to the North pole. This flow continues constantly around every magnet.

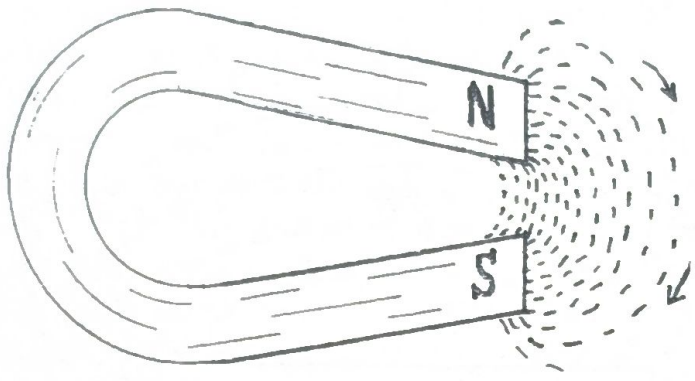


Figure 2.

There is one other law of magnetic force which you must know. The pull of a magnet on a piece of iron diminishes very rapidly as the iron is removed from the magnetic field. Whereas a needle may be readily attracted by a magnet when placed within one quarter of an inch of it, if you place the needle about two inches away from the magnet, the pullwill not be strong enough to attract the needle. The reason for this marked difference in the attractive power of a magnet is that at a distance from the magnet there are fewer lines of force pulling on the substance to be attracted. We have learned that all of the magnetic lines converge to come to a point at each of the two poles. Any magnetic substance that is held close enough to the magnet to be within range of all of these lines, will be strongly attracted because it will have more magnetic lines pulling on it than would a substance held further away.

By careful experimentation it has been learned that the force of magnetic attraction varies inversely as the square of the distance between the magnet and the object that it attracts. To give you a practical illustration of how this law operates, we will visualize a large magnet capable of attracting a one pound block of iron at a distance of one inch. Then, according to the above law, at a distance of three inches the magnet could attract only one ninth of a pound of iron. This is because the force of magnetic attraction varies inversely as the square of the distance between the magnet and the object being attracted. Since the distance is three inches, we square three (which means multiply three by itself) to produce nine. Now the reciprocal of nine is one-ninth. Hence the pull at three inches will be only one-ninth the pull at one inch. At a distance of four inches, the same magnet could attract only one-sixteenth as much weight as at one inch. At a distance of one inch it can move one pound of iron, but at a distance of four inches it could move only one-sixteenth of a pound, or one ounce.

You will now understand what is meant when we say that the field of a magnet varies inversely as the square of the distance from the pole to the point at which the pull is needed. This is a law that you must keep constantly in mind.

MOLECULAR THEORY OF MAGNETISM

If we were to take an ordinary bar magnet and cut it into two pieces, each piece would be found to have its own north and south poles. If we next took each one of these pieces and divided it into halves, we would discover that each of the smaller parts maintained north and south poles. And no matter how far we were to go in the dividing up of our magnet, we would always find that as soon as a piece is cut in half, each of the new sections has north and south poles. We could, theoretically, continue this division until we reached the smallest known particle of matter, the molecule. And if we were to do this, we would discover that each molecule was a small magnet.

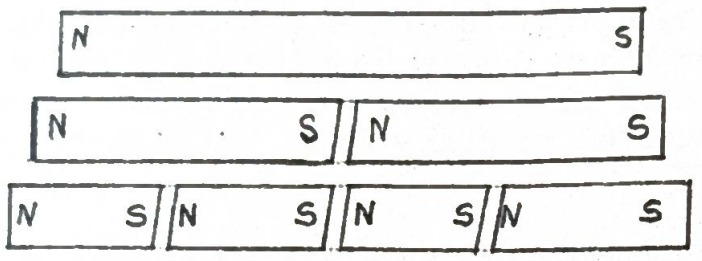


Figure 3.

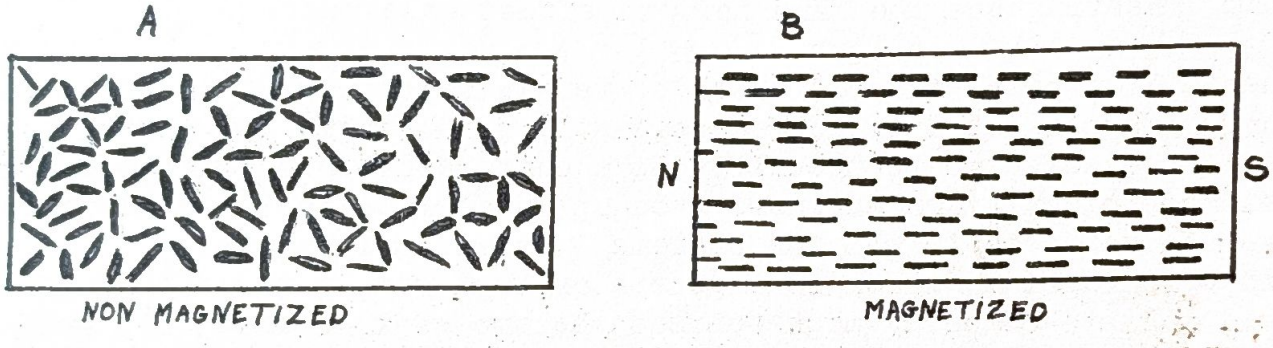


Figure4.

Scientists, in explaining this fact, assume that each molecule of steel, or other magnetic substance, normally is magnetized, and thus has its own "N" & "S" poles. They claim that the ordinary piece of steel is not magnetized as a whole merely because the molecules which form it occupy very disorderly positions, as indicated in figure 4A. The individual molecules are assumed to occupy positions as haphazard as the positions of the grains of barley in a bin. If we consider that each of these grains is a little magnet we will readily understand that the group as a whole can present no magnetic effects, because the magnetic field of any one grain would be cancelled out by the magnetic fields of the other grains. It is because the molecules of an ordinary steel bar are all jumbled up that the bar does not seem to have magnetic properties. On the other hand, when the molecules are lined up in orderly fashion, with their N poles all facing in one direction, as indicated in figure 4B, the bar is magnetized as a whole. It will then exhibit magnetic properties, such as the establishment of a field of force.

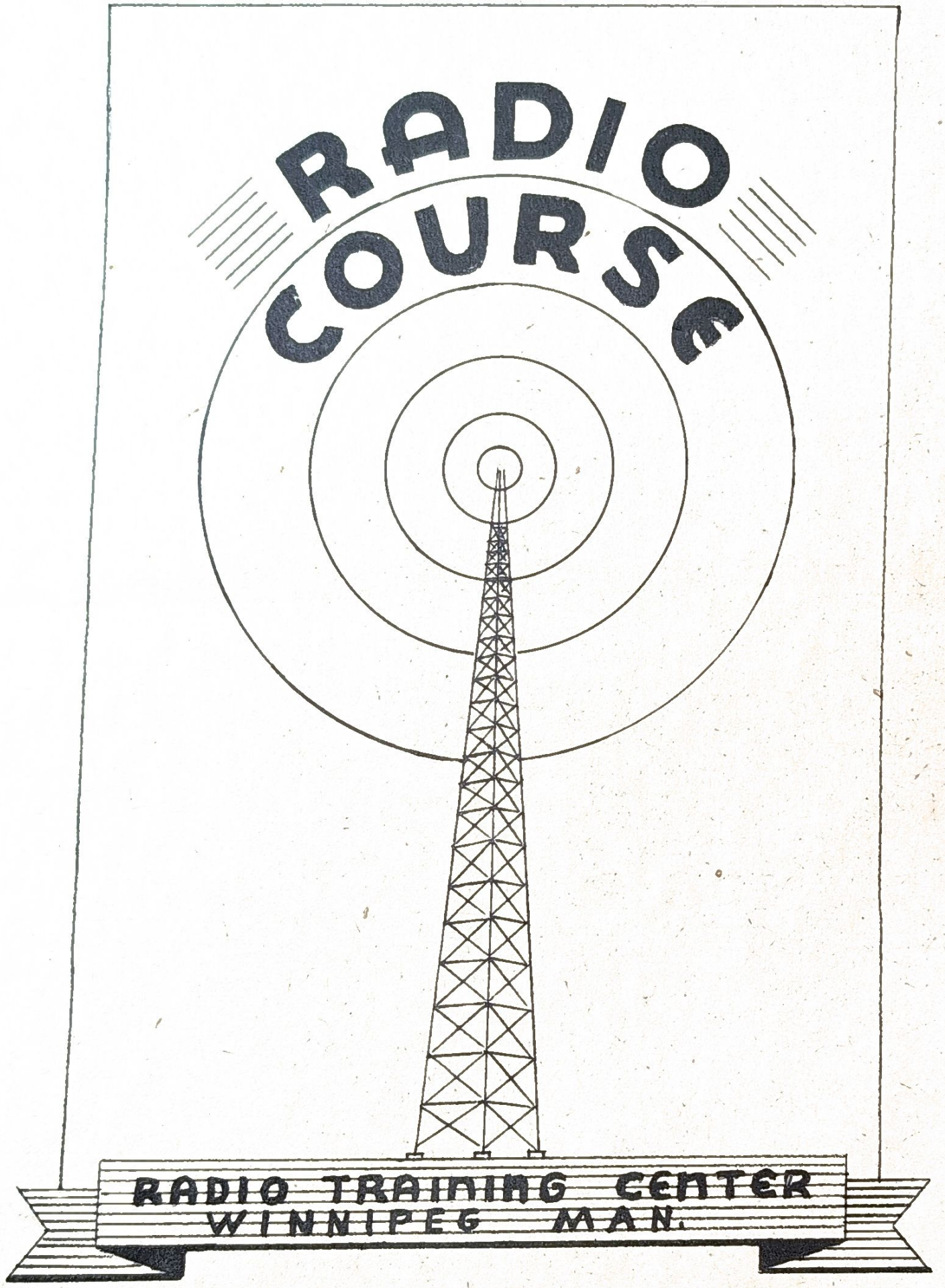
This is what we call the "Molecular theory of Magnetism". This theory states that every molecule is in reality a small magnet, but since these molecules normally are arranged in a very haphazard manner in any substance, no magnetic properties are exhibited by that substance. But in the case of a magnet, all of the molecules have been lined up and turned to face in one direction. All of the magnetic fields of the individual molecules will now be made to combine, and in this manner a complete magnet will be formed. Whether the molecules can be changed easily or not depends upon the kind of metal employed. In iron the molecules turn quite readily when placed in a strong magnetic field. But as soon as iron is takein out of the magnetic field the molecules fall back into their original places, and the iron loses its magnetism. We call such a magnet a temporary magnet. But in the case of steel the molecules cannot be turned as readily as in the case of iron. Considerable force must be exerted before the molecules may be lined up in the first place, but after the molecules are lined up they will retain their position and the piece of steel becomes a permanent magnet. After a piece of steel has become magnetized it will retain its magnetism for a great length of time.

It is not wise to hammer or jar a steel magnet, because this will tend to throw the molecules out of position and will cause the steel to lose its magnetism. Heating has the same harmful effect on a magnet.

The ability of a piece of metal to retain magnetism is called permeability. Steel has high permeability and consequently is suitable for making permanent magnets. Steel of high permeability is a comparatively recent development. Many failures of aviation engines, even up to as late as 15 or 20 years ago, were due to inefficient ignition systems. Aviation ignition is almost always supplied by a magneto, which is a generator employing permanent field magnets. The field magnets of early magnetos soon became weak because they were constructed of low pereability steel--steel that could not retain its magnetism over a long period. The development of steels of high permeability of recent years has made magneto ignition systems thoroughly reliable, and we do not think we would be far wrong in stating that this development has done more to advance the safety and reliability of aviation than anything, excepting, perhaps radio itself.

TEST QUESTIONS

1. Why are permanent magnets made from steel?
2. Explain what is meant by a magnetic field.
3. What is "Magnetic Flux"?
4. Explain the difference between a temporary and permanent magnet?
5. What do we mean when we speak about the poles of a magnet?
6. Name two common magnetic substances.
7. When two unlike poles are brought close together will they repel each other?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LESSON NINE

LESSON SEVEN

THE MAGNETIC FIELD

As the student will have probably surmised, there is a definite connection between an electrical current and a magnetic field.

If a length of wire is pushed up through a square piece of cardboard and connected to the terminals of a dry cell as indicated in Figure one, current will flow in the wire and a magnetic field will be set up around this wire throughout its entire length. This field may be detected by placing a small magnetic compass upon the cardboard through which the wire passes. The compass will now no longer point to the true North, but rather will place itself at right angles to the wire. No matter to which side of the wire the compass may be moved, this right angle position, with respect to the wire, will be held. When it is recalled that the compass consists actually of a permanent magnet, having its own "N" and "S" poles, it will be evident that magnetic action of some type must be set up by the current in the wire. That this is true will be clearly seen by opening and closing the circuit. Unscrew one terminal of the dry cell and remove the wire. Current will cease flowing in the wire and the compass needle will change position until it points again to the North. No matter where the compass may now be moved around the wire the needle will continue to point to the true North. Obviously a "dead wire" (a wire carrying no current) has no magnetic properties.

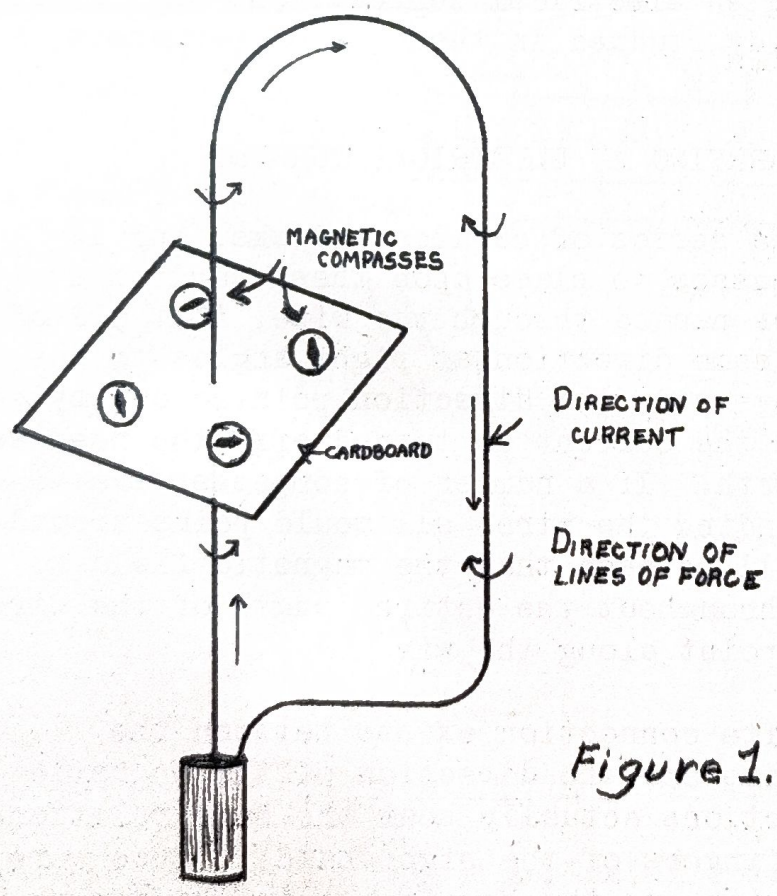


Figure 1.

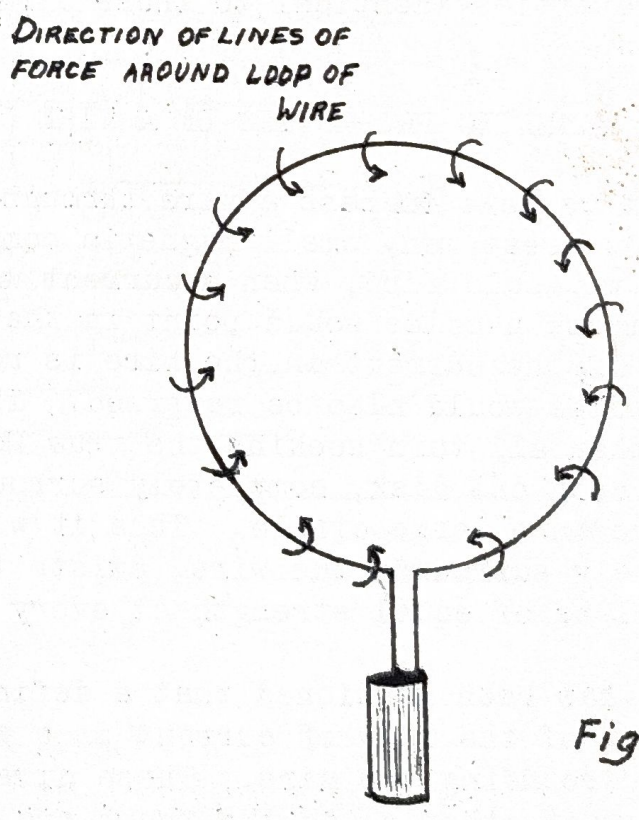


Figure 2.

Attaching the wire again to the terminals of the dry cell, current will be restored in the circuit and the compass needle will return immediately to its right angle position with reference to the wire. Now if both ends of the wire are removed from the dry cell terminals and reversed, and the electrical current thus permitted to flow through the wire in the opposite direction, what will be the action, of the compass needle? It too will reverse itself.

If the "N" pole previously was pointing in one direction, wi ll now point in the opposite direction. Thus it will be clearly seen that the magnetic properties of a wire carrying an electrical current are reversed each time the direction of the current flowing in the wire is reversed.

NATURE OF MAGNETIC FIELD INDICATED BY COMPASS

When considering the laws of magnets, we learned that if a compass, consisting of a magnetic needle, is placed in a magnetic field, the "N" pole of the compass will turn away from the "N" pole of the field and seek rather the "S" pole of the field. Similarly with the "S" pole of the magnetic needle. It will be repelled by "S" pole and drawn toward the "N" pole of the field. This force, acting as it does upon both ends of the magnetic needle of the compass, will cause that needle to "line up" with, or lie parallel to the lines of force existing in the magnetic flux in which it is placed.

Returning again to our experimental set up. When the magnetic compass was moved in a circle around the wire, the compass held fast to its position relative to the wire. That is, when the compass was moved in a circular path around the wire, the compass needle always lay parallel to the circumference of an imaginary circle drawn around the wire. Raising or lowering the card had no effect upon this action of the compass. The only things which altered the position of the magnetic needle were: (1) turning off the current and (2) reversing the current. The first severed all magnetic connection between the compass and the wire, the second reversed those connections making the compass needle completely reverse its position. Obviously a magnetic field must exist around a wire carrying an electrical current, and this field has properties identical to those already studied in the case of permanent magnets.

MAGNETIC PROPERTIES OF A WIRE CARRYING AN ELECTRICAL CURRENT

If we were to pass a wire through a series of cardboard disks, and if we had a great many small magnetic compasses to place upon these cardboard disks, we would find, when a current was passed through the wire, that all of the compass needles would point in the same direction at right angles to the wire. If the current in the wire is reversed, the direction pointed out by the needles would also be reversed. If the current is turned off, the needles would then all turn seeking the true North. If a number of compasses are placed upon one disk, completely surrounding the wire, all would point around the wire in a large circle. Thus it will be seen that the magnetic field completely surrounds the wire, exists throughout the entire length of the wire and will be of equal strength at every point along the wire.

It has been mentioned that a definite connection exists between the direction of the flow of current in a wire and the direction of the magnetic field surrounding the wire. These directions actually bear the same relationship to each other as do the thumb and fingers of the right hand. If we were to grasp a wire in our right hand, and with our thumb pointing in the direction of current flow, our fingers would then point in the direction the magnetic flux flows around the wire. This fact brings up the question of how one may tell in which direction the current is flowing in a wire. This is often not possible without the aid of instruments made for that very purpose.

However, electrical current, it is agreed, flows from the positive terminal of a battery, through the external circuit (the load), back to the negative terminal, and then through the battery to the positive terminal again. In a dry cell the central terminal (the carbon) is positive, while the side terminal (the zinc) is negative--but this matter will be considered again in greater detail.

MAGNETIC FIELD SURROUNDING A LOOP OF WIRE

If we take the length of wire used in our previous examples and bend it into a single closed loop, of say five or six inches diameter, such as is shown in Figure two, and if we connect this loop to the dry cell, current will be set up in the loop. Making use of the thumb and fingers rule, we grasp the loop in our right hand, the thumb pointing the direction of the current in the loop, and our fingers pointing in the direction of the flux lines around the wire. Now place the loop in a horizontal position. If we slide the loop around in our hand, it will become apparent that the magnetic lines surrounding the wire are flowing down inside the loop at every point and up again on the outside of the loop. This is a very important observation and should be carefully noted.

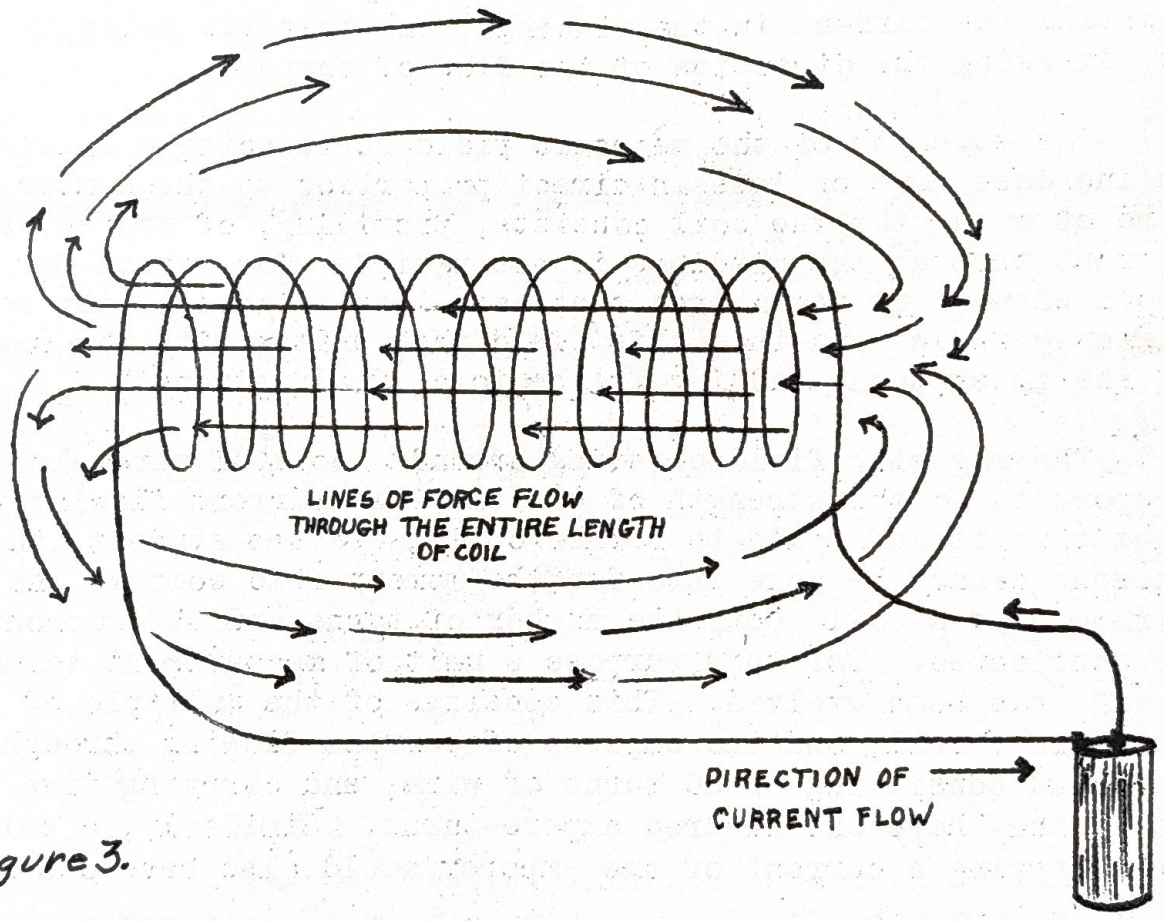


Figure 3.

MAGNETIC PROPERTIES OF A COIL OF WIRE

If we next form a series of spiral loops in our wire, so that it will present the appearance of a short coil spring, (see figure three), and again attach it to our dry cell, the complete coil (or solenoid, as such an assembly is technically termed), will assume properties similar to those of a permanent magnet. Magnetic flux will flow down inside the entire length of the coil and back again on the outside of the coil. This statement will be seen to be

quite reasonable. The magnetic lines instead of circulating around each individual turn of the coil, or section of wire, as in previous examples, now combine and flow the entire length of the coil. Thus the coil may be expected to present "N" and "S" poles as would a permanent magnet. Actually this is the case.

MAGNETIC POLES OF A SOLENOID

If the coil of wire mentioned above is laid flat upon the table, and if a small magnetic compass is placed near to one end of the coil, when an electrical current is flowing in the windings of the coil, one point of the compass will be observed to point into the coil, attracted to it as it would be attracted to the pole of a permanent magnet. If the compass is now removed to the opposite end of the coil, the other pole of the compass will be attracted to the coil, indicating that the two ends of the solenoid are of different magnetic polarity. Next, if the battery connections to the solenoid are reversed, the pole of the compass needle pointing to one end of the coil will be reversed, indicating that the polarity of the magnetic field surrounding the coil has been changed. Thus the coil will be seen to differ from a permanent magnet only in so much as it may be turned on or off by stopping or starting the current in the windings, and that its polarity may be reversed by reversing the direction of the flow of current.

The strength of the magnetic field surrounding a solenoid has been found to increase more or lesssin direct proportion to the number of turns of of wire of which the the coil consists, providing, of course, that the electrical current through the windings is not varied. The reason for this will be understood when it is remembered that each loop of wire in the coil sets up its own magnetic field, and that this field then unites with the magnetic field of all of the other turns, adding to the total field strength.

The magnetic field existing around a coil of wire also varies in direct proportion to the strength of the electric current flowing through the coil. That this is so should be rather obvious to the student, though the technical reasons cannot be gone into for the moment. To compute the magnetic field strength of a coil, both the number of turns and the current strength must be considered. For this purpose a unit of measurement termed the "Ampere-Turn", has been evolved. This consists of the multiple of the number of turns in a coil, and the amperes of current flowing through the coil. A solenoid consisting of 20 turns of wire, and carrying five amperes of current would thus have one hundred ampere-turns. Similarly, a coil with 100 turns, and carrying a current of one ampere, would also have one hundred ampere-turns.

THE IRON CORE

As has already been mentioned, Iron and Steel have the peculiar property of being good conductors of magnetic lines of force. In this, incidentally, they stand almost alone. If an iron core is placed inside of the coil, or solenoid which we have been considering, the effective magnetic field of the coil will be strengthened greatly. The reason for this is that the magnetic lines of force flow very much better in a bar of iron than they do in open air, or in any other substance.

The reluctance (opposition to the passage of magnetic flux), of iron and steel is so much lower than that of air that on electric current in a coil will set up thousands of times as many magnetic lines in an iron core as it would in air alone. Thus the effective magnetic strength of a coil is increased by the addition of an iron core. A coil, complete with iron core, is usually termed an Electro-Magnet.

MAGNETIC CIRCUITS

The folow of magnetic flux around a magnet may be considered in much the same manner as the flow of an electric current. In an electric circuit we have pressure (Voltage) that forces the current through the resistance of the conducting path and the load. The flow of magnetic flux may be considered in much the same manner. It should be understood that although magnetic flux does not absolutely require a metallic conductor, as does an electrical current the presence of a conducting path of iron greatly increases the flow of magnetic flux. The external pathway of magnetic flux is always from "N" to "S" poles of the magnet, and from "S" to "N" poles INSIDE the magnet. The driving force. corresponding to E.M.F. in electrical circuits, is known as magnetomotive force, or simply as M. M.F. Opposition to the flow of magnetic flux is termed Reluctance.

In detailed comparison with electrical terms, we have:

Current (the flow of electricity)	Flux (the flow of magnetism)
E.M.F. (Electrical pressure)	M.M.F. (Magnetic pressure)

Resistance (opposition to the flow of electrical current)
Reluctance (opposition to the passage of magnetic flux)

STRENGTH OF MAGNETIC FLUX -- THE SATURATION POINT

Flux strength of a magnetic circuit may be stated as being equal to the M.M.F. divided by the reluctance of the circuit. Iron is a very good medium for carrying magnetic lines of force, but it should be evident even so that some limit must exist to the number of lines of force which may be carried by any given piece of iron. This is perfectly true, and as magnetic flux is steadily built up, the ability of the iron to carry the increased flux load will decline. Eventually a point will be reached at which no further increase may be made in flux carriage without tremendously increasing the current required to set up the magnetic field. The iron will have absorbed all of the magnetic lines of force which it can well absorb, and will have reached what is known as the "Saturation Point".

The most important thing to remember in all of this is not that a saturation point can eventually be reached when electrical current in a magnet is increased, but rather that the strength of the magnetic field varies normally (that is when the saturation point is quite distant) more or less in direct proportion to the strength of the electric current in the magnet windings. If this were not so, electrical reproduction of the human voice, in recognizable form, would be quite impossible.

FORMS AND USES OF ELECTRO-MAGNETS

Every electric motor, every generator, every radio head set or loud-speaker, every telegraph instrument, and every door bell or buzzer, is based

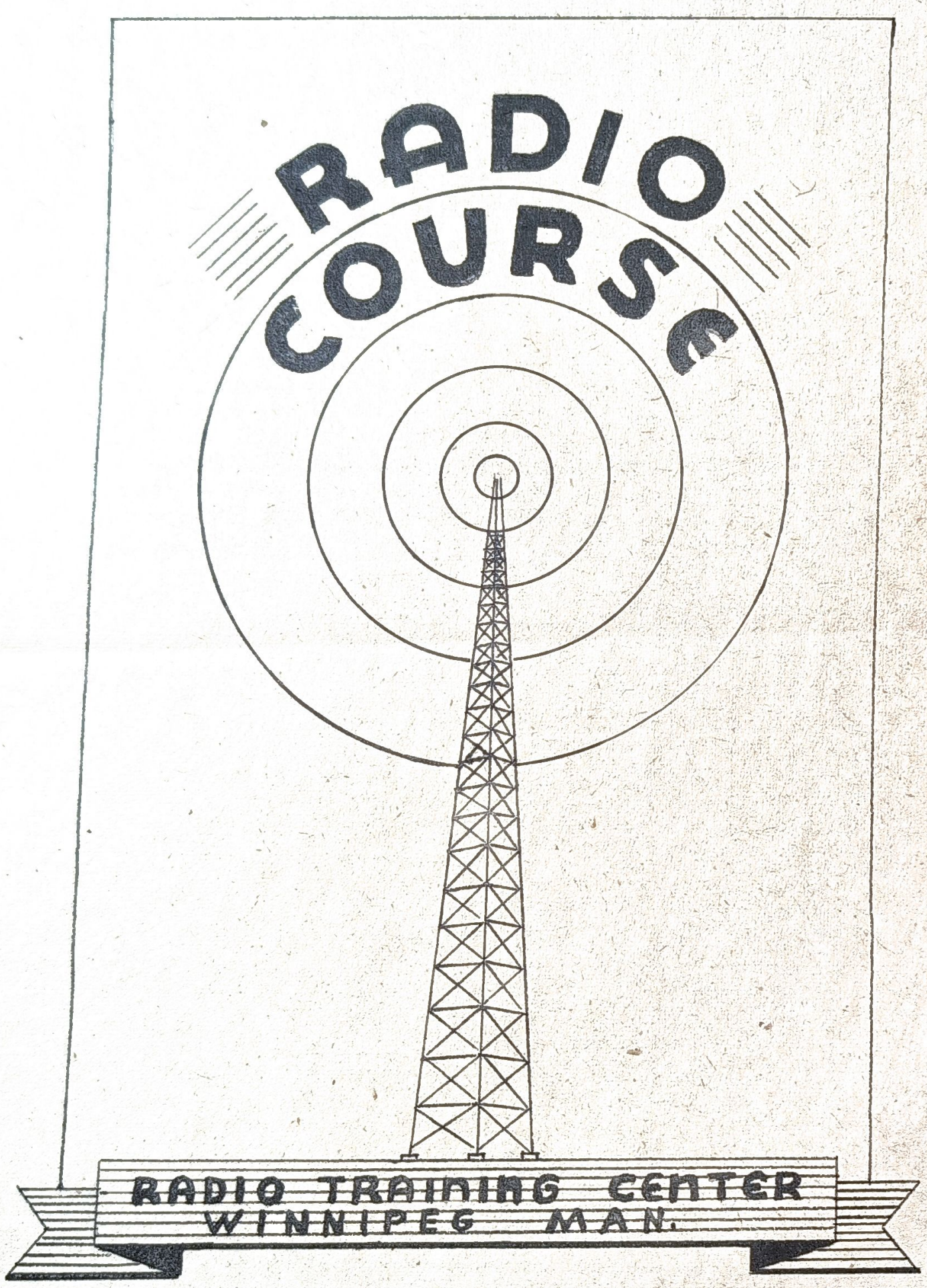
largely upon magnetic action. And there are literally thousands of other uses for magnetic circuits. The magnets employed are not always electro magnets, but these being far more flexible and adaptable than permanent magnets are used most often. Magnets vary in size all the way from the minute deflection coil of a very sensitive meter, to the gigantic electro-magnets used to load steel rails, scrap iron, and other iron objects. Generally speaking, whenever mechanical motion is to be produced by electrical means, some form of electro magnet will be found on the job.

INDUCTION

Take one specific example: the student must have seen at some time or other the old vibrating type of induction coil, at one time used very extensively in connection with automobile ignition circuits. In this type of induction coil a straight line iron core magnet is employed. One end is exposed and an iron or steel vibrator is placed close to this end. When no current is flowing in the coil, the vibrator springs away from the core tip, closing the circuit. If a battery is attached, this will cause a current to flow in the coil, magnetizing the core and drawing the vibrator into close contact with the core tip. The circuit will now be broken, the core will be demagnetized, and the vibrator released. The vibrator then flys back to its original position, closing the circuit again. In this manner the cycle is repeated. How this stopping and starting of a current in a coil may give rise to a high intensity spark, must be left for detailed consideration in a later lesson. For the moment it will be sufficient to state that this action is based upon the fact that magnetic flux is set up by the current flowing in the coil. Actually two coils are employed which are closely related to one another. The flow of the simple six-volt current in the first mentioned coil (the primary) actually "induces" a tremendously higher voltage into the second coil (the secondary), and it is this high voltage which causes the "spark". This phenomenon, known as "induction", is almost the backbone of radio. We will learn a great deal more about it in the following lessons.

TEST QUESTIONS

1. What two things affect the strength of a magnetic field surrounding a coil?
2. Is copper a good conductor of magnetic lines of force?
3. Will the "N" pole of a magnetic compass be deflected by the "N" pole of a magnet?
4. Will the magnetic compass needle be affected by the approach of a non magnetic object, say for instance a short piece of copper rod unattached to any source of electrical energy?
5. Will an electrical conductor attached at one end to a battery terminal, and free at the other end, be surrounded by a magnetic field?
6. Is air a conductor of magnetic lines of force?
7. Does the magnetic field surrounding a solenoid magnet have polarity?
8. Define briefly the ampere-turn.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LESSON TEN

CHEMICAL GENERATION OF ELECTRICITY

Scientists have for many years divided electricity and electrical activity into two separate classifications---static electricity and dynamic electricity. This we do not believe is a very wise classification because it tends to create the impression that static and dynamic electricity are different types of energy. This is not true. One would scarcely think of water in a glass as being different, chemically or physically, from the torrent pouring over a falls One is water in motion, the other water at rest---that is all. Similarly with static and dynamic electricity. Electricity at rest is termed static electricity, and electricity in motion, dynamic electricity. The distinction is entirely one of activity, not of form.

POTENTIAL DIFFERENCE

An electric current, we now realize, consists of a flow of electrons, usually in a wire, between a point at which there is an excess of electrons and a point at which there is a deficiency. Scientists have formulated a term "Potential Difference" to describe the difference which exists between these two points. A potential difference may be created by any one of three different methods: (1) Altering the number of electrons in the molecules of a body through friction, (2) Chemical action, and (3) Electro magnetic induction.

STATIC ELECTRICITY

The well know static electricity is a manifestation of the simplest form in which a potential difference may exist. To say that there is an electrical potential difference between two objects means simply that one object has an excess of electrons while the other has a deficiency. Should the two be connected by a conductor, an electrical flow will take place and continue until the number of electrons in each has been equalized, eliminating the potential difference. Static electricity is the form in which electricity was first known, and the first electrical flow was produced between two objects which had been made to assume different electrical charges by frictional means.

Some objects may be electrically charged by rubbing them briskly with a piece of silk cloth, or similar substance. Several objects, such as glass rods, bars of sealing wax, or hard rubber, show marked electrostatic properties, and may be made to assume electric charges quite easily. Charges generated by means of this rubbing operation are termed frictional electricity, due to the fact that friction causes the objects to lose electrons. Actually electrons are rubbed off by the silk cloth, leaving the objects with less than the normal quantity of electrons, and therefore bearing positive charges.

It is interesting to note that it is only objects which are electrical insulators, or which are supported on insulating bases, which may be made to assume electrical charges in this manner. The reason for this fact is simple enough. In attempting to charge metallic articles (conductors) electrons would be carried from some other object as fast as they were rubbed away by the cloth, making it impossible for the metallic object to acquire a charge.

When a glass rod or other object is charged by frictional means, small pieces of tissue paper will be attracted by the rod, and will actually jump

to it over a considerable distance. In this case a neutral object is attracted to a charged one and this attraction is due to the fact that the free electrons of the tissue are attracted to the charged object, but, because they cannot rush across vacant space, they cause the whole tissue to move to the charged rod.

If a stick of sealing wax is suspended at the centre by a thin silk cord, and then charged by rubbing with a piece of silk cloth, this bar of wax will be attracted to a charged glass rod brought near to it. In this manner two charged bodies may attract each other. But Electrostatically charged objects do not always attract. If a piece of sealing wax, charged by rubbing, is brought near to the previously charged bar of sealing wax suspended by a silk cord, the two will repel each other.

Thus it is seen that some electrostatically charged objects are repellent, while others attract each other. But why should there be a difference? Obviously there must be some law governing this matter. Early experimenters came to the conclusion that different objects assumed different types of charges, but it was not until the electron theory was thought of that a really plausible explanation was found. According to the electron theory when some objects are rubbed with a silk cloth, electrons are removed from these objects leaving them with a reduced number of electrons and consequently bearing a positive charge. The excess electrons in this case will appear upon the silk cloth, causing it to be charged negatively. But there are other objects, which when rubbed in much the same manner with a silk cloth, actually remove electrons from the silk. In this case the object rubbed by the silk assumes a negative charge, due to the fact that the number of electrons on it is increased. Why the rubbing of some objects increases the number of electrons, is not entirely clear.

The sealing wax rod which was suspended by a silk thread, in an earlier example, was negatively charged. On the other hand, the glass rod to which this sealing wax bar was attracted, was positively charged. In the second example, in which two sealing wax bars repelled each other, the bars were both negatively charged. From these observations the following laws of electrostatic electricity may be formulated:- (1) Bodies bearing similar electric charges repel each other. (2) Bodies bearing dissimilar electric charges attract each other.

THE ELECTRON THEORY APPLIED TO ELECTROSTATIC CHARGES

In an earlier lesson we learned that all matter is comprised of atoms and that these atoms are made up of negative and positive charges, termed electrons and protons. Ordinarily the number of electrons in an atom is exactly equal to the number of protons, and, therefore, the atom normally is strictly neutral.

In order that a body may be charged positively or negatively, the number of electrons in the atoms of that object must be respectively reduced or increased. A body which is positively charged has a scarcity of electrons and for this reason tries to attract to it electrons from any object with which it may come in contact. On the other hand a negatively charged object has an excess of electrons and therefore has a tendency to repel other electrons.

It is for this reason that two negatively charged objects repel each other, while a body having a negative charge will try to move toward a positively charged object, in order to make up this deficiency.

CURRENT ELECTRICITY

No one has ever seen an electron, or an electric current, but we all have seen a section of tissue paper jump to a charged fountain pen. This simple action is an amazing electrical phenomenon and one which leads directly to the formulation of the electron theory--for in this action all of the forces which make an electric current flow may be observed. We have assumed that electrons rush with great speed from a negatively charged body to a positively charged object. This rush of electrons may be very powerful and capable of doing considerable useful work. This power is represented by a difference in electrical potential existing between the two charged objects. If the objects are not connected by a conductor, no electrical flow will take place. But clearly the same power must remain--the same attraction of the positively charged object for the excess electrons of the negative object will exist, and this power, if sufficient, may draw the two objects together. Understand that this attraction between the two bodies is in many respects identical to a flow of electric current. An electric current arises due to the fact that electrons wish to move from a negative object to a positive object. If the two are connected by a conductor the electrons merely flow in that conductor and spend their power in heat. In the case of an actual bodily movement the force which comes into play is identical. The excess electrons from the negatively charged object wish to reach the positive object, but, due to the high resistance of the intervening space, cannot bridge the gap by a spark, or direct flow of electrons. Yet, because the attractive force continues to exist, the two bodies may be drawn together.

How two electrostatically charged objects may be the source of a flow of electrons, or an electrical current, is quite clear. An electrical potential difference exists because there are more electrons on one object than on the other, and an equalizing flow thus takes place. In the case of simple objects electrified by frictional or other means, current will flow only temporarily, or until the potential difference has been eliminated by the movement of excess electrons from the negative body to the positive. This is always the case when objects have been electrified by external means.

We will learn a great deal more concerning electrostatically charged bodies in subsequent lessons. For the moment it will be sufficient to know that the round about system of charging a body by friction, and then utilizing the potential difference thus set up to create an electric current is seldom considered a practical method of generating electricity. However, there is one interesting exception to this rule. In the scientific laboratories high d.c. voltages are often needed. Large X-ray machines too require large d.c. voltages. But, for reasons which will be discussed later, it is highly impracticable--well nigh impossible--to produce extremely high d.c. voltages, of the order of a million volts or more, either from batteries or from the more common types of electric generating machines. For this reason scientists have turned to the very old electrostatic machine in order to produce these voltages. In this type of machine, electrons are swept away from a revolving disc by friction and are allowed to accumulate as a charge upon insulated metal plates in an assembly known technically as a "condensor". No limit

exists to the voltages which may be built up by this device, other than the limits imposed by the imperfections of insulation throughout the machine, particularly between the condenser plates.

In addition to the frictional means of creating a difference of potential, potential differences, or voltages, may be created in two other methods--by chemical action, and by electro-magnetic induction. The subject of electro magnetic induction, as it applies to the generation of electricity, will be considered in Lesson 11. For the moment we will consider only the chemical means of creating a potential difference.

ELECTRO-CHEMICAL ACTION

Current electricity will flow between bodies bearing different electro-static charges due to the fact that one holds more electrons than the other, but the flow of current will cease the moment the two become equalized. Now it must follow from this that if, by chemical means, two bodies could be kept at a difference of electrical potential, that is, in a condition in which one continuously had an excess of electrons while the other had a deficiency--then the resulting potential difference would be steady, making possible a continuous flow of electric current.

Early experimenters discovered that many different substances possessed marked electro-chemical properties and ould be utilized, in proper chemical relationship, to produce an electrical potential difference. This action may best be illustrated by describing the old fashioned wet cell which was the for runner of the modern dry cell, and is, from the chemical standpoint, very similar.

The old fashioned wet cell is is illustrated in figure one. It consists of two electrodes of different metals, usually zinc and copper, which are immersed in a dilute solution of sulphuric acid known as the electrolyte. In this type of cell the two metal electrodes are insulated from each other, excepting for the contact of the acid solution. If wires are connected to the two electrodes and to some external circuit, electric current will be found to flow in this circuit. The potential difference existing between the two electrodes arises out of the chemical action taking place in the cell and is due to the fact that the metals from which the electrodes are selected have different electrical properties, are situated at different positions in the electro-chemical scale.

The Italian experimenter Volta discovered that all metals bear certain electro-chemical relationships to one another, and that different combinations of metals in the simple chemical cell produce different voltages. The size, or shape, or spacing of the electrodes he discovered, made little difference, and the voltage arose from a difference in characteristics of the metals themselves. . Table No. 1 shows a group of common materials and the electrical potential difference which exists between each of these and zinc. Zinc is commonly used as the negative plate in electro-chemical cells because a large potential difference exists between it and other substances, particularly carbon, and for this reason all substances are considered with reference to it.

TABLE ONE

Zinc	0.	volts	Copper	1.05	volts
Iron	.35	"	Silver	1.45	"
Hydrogen	.35	"	Gold		
Lead	.70	"	Carbon	1.75	"

Returning now to a consideration of the simple wet cell. It consists of zinc and copper electrodes immersed in a dilute solution of sulphuric acid, usually consisting of four parts water to one of acid. In this cell the zinc is the negative terminal and the copper positive. From Table No. 1 we see that the electro potential difference existing between these two metals is slightly better than one volt.

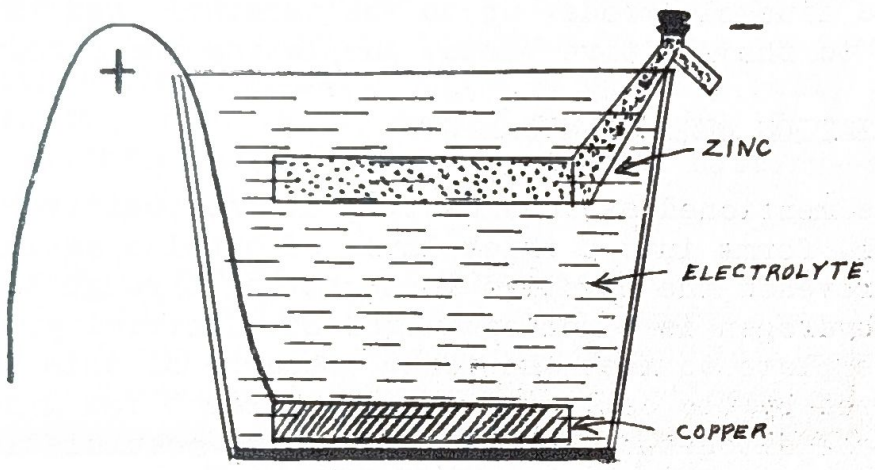


Figure 1

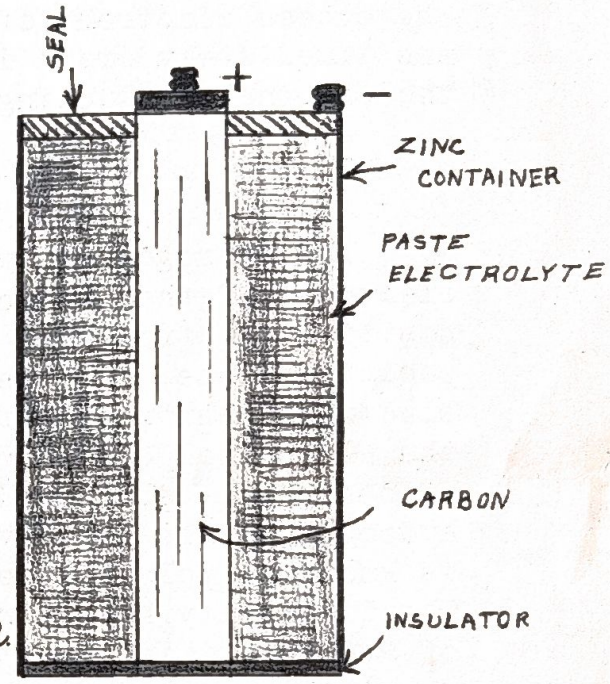


Figure 2

From our understanding of the electron theory, we will expect a great quantity of electrons to accumulate on the negative terminal of this cell, while the positive terminal will lose many of the electrons it formerly held. This is true, and the difference of electron placement--displacement of electrons from the positive and forcing them to the negative terminal--is brought about in the following manner: The electrical potential difference set up between the electrodes of the chemical cell is the product of chemical ionization taking place in the electrolyte of the cell. The subject of ionization will be dealt with again when we consider the actions taking place in a vacuum tube. The ionization occurring then, however, is a product of electrical action. But the ionization taking place in the electric cell is a product of chemical action. Thus we have chemical ionization, producing electrical effects, and electrical ionization, producing, usually, chemical effects. One is, in a sense, the reverse of the other.

An ion is a molecule having either an excess or a deficiency of electrons and in the electric cell is produced in the following manner. The sulphuric acid of the electrolyte, due to chemical action, breaks up into positively charged hydrogen ions and negatively charged ions which are a combination of oxygen and sulphur. (Sulphuric acid is written H_2SO_4, and is a combination

of hydrogen, oxygen and sulphur.) The positively charged hydrogen ions, lacking electrons, move over to the copper plate where they absorb electrons from the copper, neutralizing themselves, and leaving the copper plate with a deficiency of electrons. The hydrogen ions, now being neutralized, appear as free hydrogen gas at the dcopper electrode. The copper plate, because it has given up electrons to the hydrogen ions, becomes positively charged. If now a conducting path is formed between this positively charged plate and the zinc plate, electrons will rush through the wire toward the positive plate in order to supply the deficiency existing at the positive plate. Now, as electrons are clearly not created in the cell, there must exist some source of supply capable of continuously feeding electrons to the zinc plate. This is true. The sulphuric acid, we said, breaks up into positive and negative ions and the electrons which the positive ions lack are actually a part of the negative ions. The negative ions move toward the zinc electrode where the sulphur and oxygen enter into combination with the zinc of the electrode. The excess electrons of the negative ions are released in this process and are immediately drawn into the zinc electrode, up to the terminal, and through the external conducting wires to the positive plate, completing the circuit.

POLARIZATION OF A CHEMICAL CELL

The hydrogen gas which we mentioned as accumulating at the positive electrode of the chemical cell, forms into a thick layer of bubbles against the positive electrode and thus prevents the negative ions getting through to the positive plate, and, because hydrogen is a non-conductor of electricity, electrons cannot flow from the plate to meet the ions. Because of this fact, the electrical current generated by the cell will decline after a few minutes of operation, and possibly cease altogether. This action--the accumulation of hydrogen on the positive electrode and the resultant reduction of current--is known as polarization and once was a serious defect of chemical cells. The difficulty has, however, been successfully eliminated by the introduction of a depolarizing agent into the cell. This depolarizing agent consists of a chemical, usually manganese dioxide, which absorbes the free hydrogen as it is formed and thus prevents it from accumulating on the positive electrode.

THE MODERN DRY CELL

The so called dry cell now in common use operates on a principle similar to that which has been outlined in connection with the old-fashioned wet cell. The "dry cell" is, of course, not really dry. A moist electrolyte is absolutely necessary or no chemical action will take place. Actually the electrolyte is made up in a paste-like form and the top of the cell is sealed over to prevent this paste from drying out entirely. A typical dry cell is illustrated in figure two.

The electrodes used in the dry cell are of zinc and carbon, and the reason for making this selection, rather than zinc and copper, is that higher voltages will be set up between carbon and zinc than between copper and zinc. The zinc electrode is cylindrical in shape and forms the outside casing of the cell. The carbon electrode is situated at the centre. The cell is filled with a paste-like electrolyte which consists of a sal-ammoniac solution in a granular carbon filler, to which has been added the depolarizing agent, manganese dioxide.

PRIMARY AND SECONDARY CELLS

Electric cells producing electricity by chemical action may be grouped into two general classifications, namely, primary and secondary cells. A primary cell is a type which derives its power directly from chemicals contained in the cell. The secondary cell on the other hand obtains power from an external source of electrical current. Electricity is, apparently, stored in the secondary cell, and, for this reason, it is often referred to as a storage cell. The se condary cell operates on a fundamentally different principle from that of the primary cell and this principle is worthy of detailed consideration.

The common storage battery, utilized in connection with automobile ignition, consists of a group of three single cells connected in series, and is correctly termed a battery. The word "battery", incidentally, means simply a group of things working together for one purpose. It is well to remember that a single electric cell--say a single dry cell, or a 2-volt storage cell--could not be correctly termed a battery. It is only when two or more cells are connected together that we have a battery--actually meaning a battery of cells.

But to return.... Primary cells have already been considered. The standard dry cell is the best and most common example of this type. It uses up its substance in the course of giving off electricity, and when it is dead it must be discarded. A secondary, or storage cell, on the other hand, may be renewed by simply passing an electrical current through it for a period of time. The distinction between a primary and a secondary cell, then, is that a secondary cell may be recharged by electrical flow, but a primary cell cannot.

Electricity is not stored in the so called storage battery. Electrons flowing in at one terminal, in the process of charging, flow right on through and out again at the opposite terminal. These electrons cause a chemical change to take place in the battery and make it possible for the battery to act as a source of E.M.F. The cell, when being charged, acts as it were storing up electricity, but this is not strictly true, and it is well to remember that the secondary cell actually gives off electric current as a result of chemical action. However, the chemical action is reversible, and thus differs from the action taking place in a primary cell.

THE STORAGE CELL

There are two types of storage battery in general use. One is the common lead plate cell, utilizing a sulphuric acid electrolyte, the other, the nickel, iron alkali cell known as the Edison cell.

Practically all of the storage batteries in use today are of the lead plate variety. The ordinary 6-volt storage battery consists o f a group of three lead-plate cells which are so constituted that a flow of electricity through the cells will restore the chemicals in the plates to an active condition, setting up a voltage difference between the terminals.

A typical storage cell consists of several positive and several negative plates, interfingering, and separated only by thin wooden or composition

separators which permit free passage of the electrolyte. The lead plates are cast in the form of grids, having holes, or grooves, which are packed with a paste made from litharge, a form of red lead. The plates of each cell are divided into two groups one of which is connected to the positive terminal, and one to the negative terminal. The whole is immersed in a dilute solution of sulphuric acid. The battery is next put on the charging line and an electric current (d.c.) allowed to flow through it for a considerable length of time. By this charging process the paste in one group of plates is converted to spongy lead, while the paste in the other plates is reduced to lead peroxide. The cell is now charged, and may be used as a source of E.M.F. The spongy lead plates form the negative and the lead peroxide plates the positive of the cell. The voltage of each cell will be slightly better than two volts, and the current produced will be in the opposite direction to which the charging current flowed.

CHEMICAL ACTION IN THE LEAD CELL

When a lead cell is freshly charged and placed in use, the acid of the electrolyte commences to act upon the material of the plates, ionization of the electrolyte takes place, and a current flow is set up. The acid enters into combination with the spongy lead of the negative plate, producing lead sulphate and water. As the discharging process goes on--i.e. as the battery is used more and more and commences to run down, the acid disappears from the electrolyte, all of it being absorbed into the lead plates.

The acid of the electrolyte enters into combination with the active material of the plates, giving rise to a current flow. The action is reversible. When the cell is discharged and placed on the charging link, and a current forced through the cell in the reverse direction, the lead sulphate of the negative plate is actually broken down into sulphuric acid and the original spongy lead. Or, as the action is more often described, the current drives the sulphuric acid out of the plates back into the electrolyte, restoring the active material of the cell, and making it once more capable of generating an E.M.F.

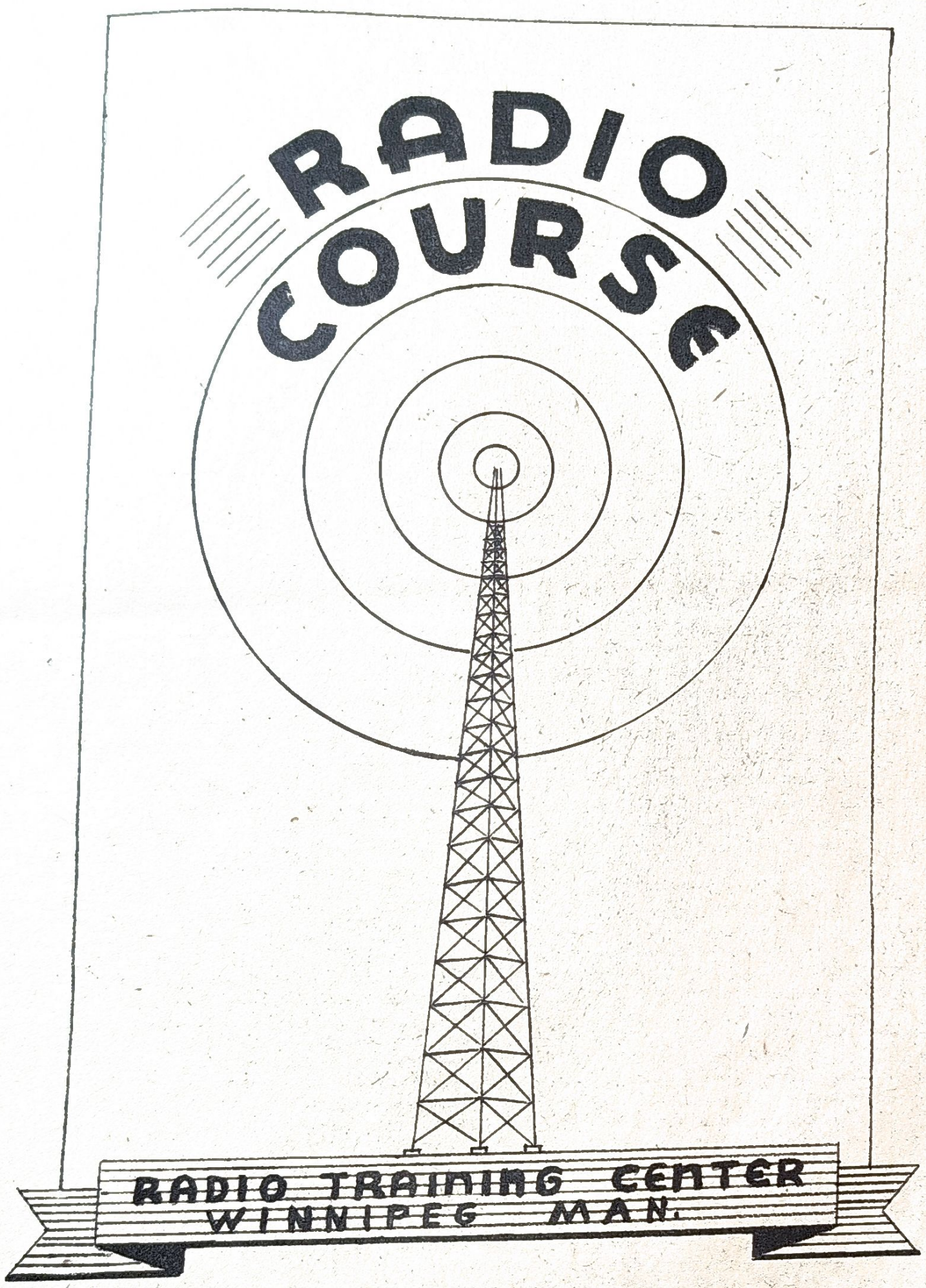
One characteristic of a rundown cell is the thinness of the electrolyte. It will have a very low acid content, and, as the specific gravity (weight per unit of volume) of sulphuric acid is heavier than that of water, the condition of charge or discharge of a lead cell may easily be determined by taking the specific gravity reading of the electrolyte. A special instrument known as a hydrometer is used for this purpose. It consists of a glass tube fitted with a rubber bulb by means of which the electrolyte of the cell may be drawn up into the tube. In the tube is a small weighted float graduated to read from 1.100 at the top, to 1.300 near the bottom. When the tube is filled with battery electrolyte, the float will rise high if the liquid is heavy indicating the presence of much acid. In a lighter l iquid it will sink lower. As the acid content in the electrolyte is a very good indication of the degree of charge in the cell, the s.g. reading may be interpreted directly as a condition of charge. A specific gravity reading between 1.250 and 1.300 will indicate a reasonably good charge, while a reading of less than 1.150 indicates a very weak charge.

THE EDISON CELL

The Edison cell is a type of storage cell used largely for marine service. It has many advantages over the lead plate cell, the chief of which is its long life. The electrodes are more complex than the simple grids of the lead plate cell. The positive plate in the Edison cell consists of nickelous hydroxide and flake nickel packed into tubes held to a light metal frame. The positive plate consists of pure iron mixed with 6% of yellow oxide of mercury, placed in the perforations of a light metal frame. An alkaline electrolyte is employed. This consists of a solution of potassium hydroxide to which has been added flake nickel. The alkaline electrolyte does not corrode the plates and makes for longer battery life. The voltage of each individual Edison cell is only slightly better than one volt and for this reason a complete battery must have almost twice as many cells as a lead plate battery of similar voltage.

TEST QUESTIONS

1. What would be the voltage of a chemical electric cell in which the electrodes are formed of zinc and lead?
2. Explain briefly why a positively charged object is attracted to a negatively charged object.
3. How is polarization eliminated in a modern dry cell?
4. Can an electric charge be produced by friction?
5. What is the difference between static and dynamic electricity?
6. Explain briefly what is meant when it is said that an electrical potential difference exists between two objects.
7. Do like electric charges attract each other?
8. Explain briefly what constitutes a flow of electric current.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LESSON ELEVEN

GENERATION OF ELECTRICITY BY ELECTRO MAGNETIC INDUCTION

By far the greater part of all electricity in common use is produced by electromagnetic induction in mechanical devices known as electric generators or dynamos. By means of a mechanical generator, electric power may be obtained directly from any known power source--water power, steam power, gasoline, diesel power, etc. Electromagnetic induction is the third of our group of three methods of producing electrical power, and it is probably the most important. For this reason it will be advisable for us to consider carefully the fundamental principles involved.

The simplest experiment to produce a current by induction is illustrated in figure one. A coil of wire, consisting of several hundred turns wound over over a hollow paper tube, is connected to the terminals of a very sensitive milliameter, or galvanometer. If one end of a permanent magnet is now thrust rapidly down into the centre of the coil, a momentary current flow will be noticed in the meter. This current will cease the moment the magnet comes to rest, and thus indicates that the electrical flow is produced by the act of thrusting the magnet into the coil. In removing the magnet from the coil, current will also be observed to flow momentarily in the circuit, but this time in the opposite direction. Currents produced in this manner are known as induced currents, and the electrical action responsible is "electromagnetic induction", usually spoken of simply as "induction".

Induction is caused by the magnetic lines of force which surround the bar magnet cutting across the turns of wire in the coil. The action may be better understood by considering Fig. two. In Fig. two a single wire is forced through a strong magnetic field existing between two magnetic poles. This single wire passing through the magnetic field will produce only a very feeble current and a very sensitive meter will be necessary to record the current at all. But being simple, the set up is an excellent one for the purpose of illustration and much valuable knowledge may be obtained from experimenting with it.

If the wire is moved rapidly up and down in a direction at right angles to the flow of magnetic flux (in the direction of arrows 1 & 2) current will be set up in the wire during the periods the wire is in motion--that is to say , when the wire is actually cutting the lines of force. When the wire is moved downward through the flux, the current flow in the wire will be in one direction. When the wire is brought back up through the flux, current flow will be in the opposite direction, indicating that thedirection of current flow is governed by the direction of movement of the wire considered in relationship to the direction of flow of the magnetic flux. If the wire is now moved in a direction parallel to the lines of force (in the direction of arrows 3 & 4) no voltage will be set up in the wire at all, showing clearly that if the wire does not cut the lines of force, no current will be induced into the wire. In moving the wire through the magnetic field in a diagonal direction, a voltage will be set up, but this voltage will not be as great as the voltage set up when the wire was moved so as to cut the lines of force at right angles.

From these simple experiments the following conclusions may be reached. When the wire cuts the flux lines at right angles, the the greatest voltage

will be induced into the wire. When the wire cuts the flux lines at any thing less than right angles, lesser voltages will be set up. If the wire is moved in a direction parallel to the lines of magnetic flux and does not cut the flux at all, no current will be set up. Apparently, then, if induction is to be great, the wire must cut as many lines of force as possible, and in a direction as nearly at right angles to the direction of the flux lines as possible.

Next let us experiment with the speed of movement of the wire. If the wire is moved slowly through the flux in a direction at right angles to the flux, only a feeble current will be produced. If the wire is moved through the flux at twice this speed, twice as much current will flow. Moving the wire more and more rapidly will produce ever greater currents. Clearly the speed of motion also effects the strength of the induced currennt.

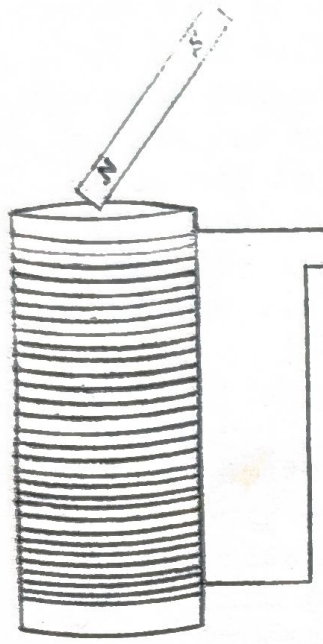
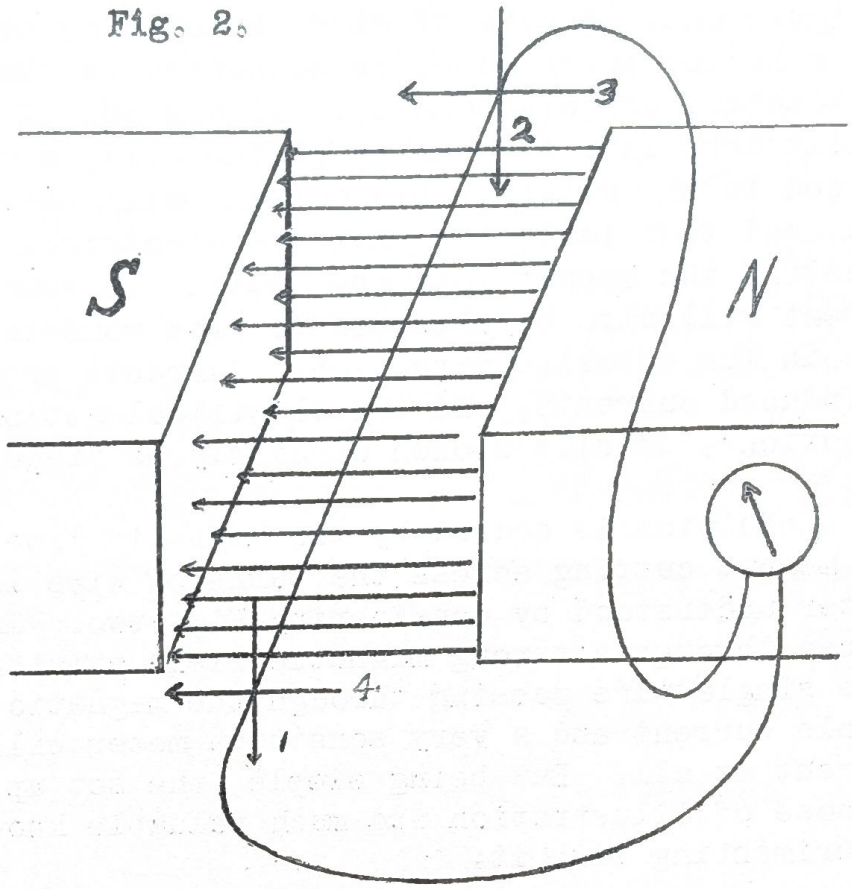


Fig. 1.

Fig. 2.



ELECTRIC GENERATOR

This principle of cutting the magnetic flux with a moving wire is made use of in the ordinary electric generator or dynamo. The fundamental principle of the dynamo is illustrated in Fig. three. Here a single loop of wire is revolved between the poles of a large permanent or electro magnet. The loop revolves on dotted axis E.F. The two ends of the loop are brought out to what are known as slip rings, which are actually sliding contacts, by means of which electric power in the loop may be brought out to the external circuit. As the loop is rotated one side will move upward through the magnetic flux, while the opposite side is moving downward.

Recalling what we have already learned in connection with the single wire in a magnetic field, it will be seen that electric currents will be induced into both sides of the loop simultaneously, and although these currents will be flowing in opposite directions--from A to B in side x, and from C to D in side y--because the wire doubles back on itself in the opposite side, the

two currents will add to one another, and, in effect, a single current will be set up in the loop, flowing from A to B from B to C and from C to D, completely circling the loop.

Understand this situation. Although the currents in the two sides flow in opposite directions, the two sides of the loop are in series with one another, and hence the current from one side will flow back through the opposite side in the same direction as the current actually induced into that side. From this observation it should be clear that the voltages of both sides of the loop add to, or reinforce, one another.

In rotating this loop, the section forming one side (A-B for instance) will rise from the bottom to the top, cutting flux all of the way, run a short distance in a direction parallel to the flux lines, and then commence to move downward again through the flux. From this observation two facts become apparent. One is that there will be a dead period during each revolution of the loop during which no current will be induced into the loop--

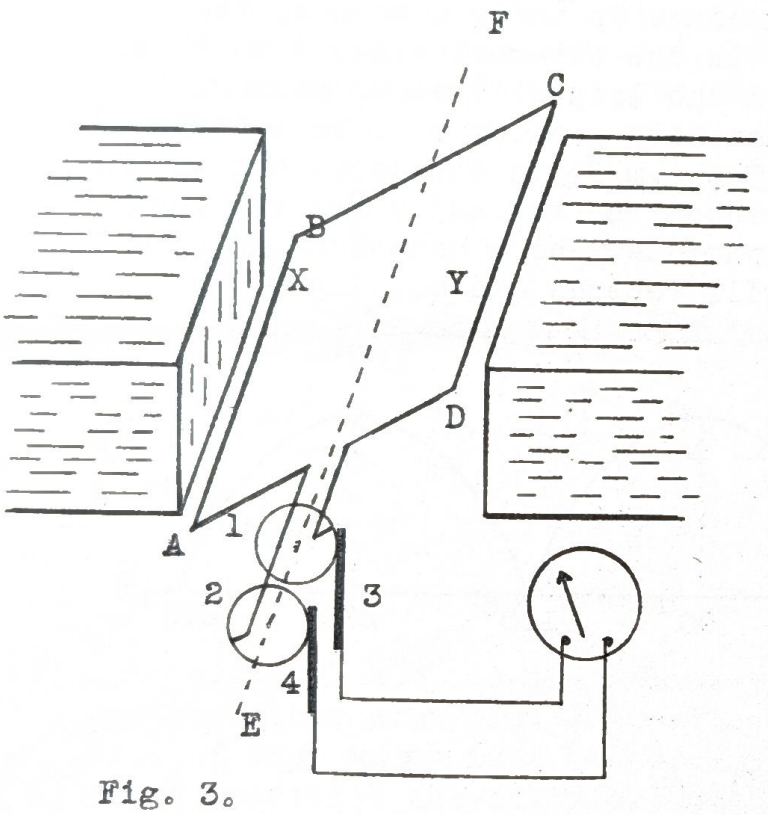


Fig. 3.

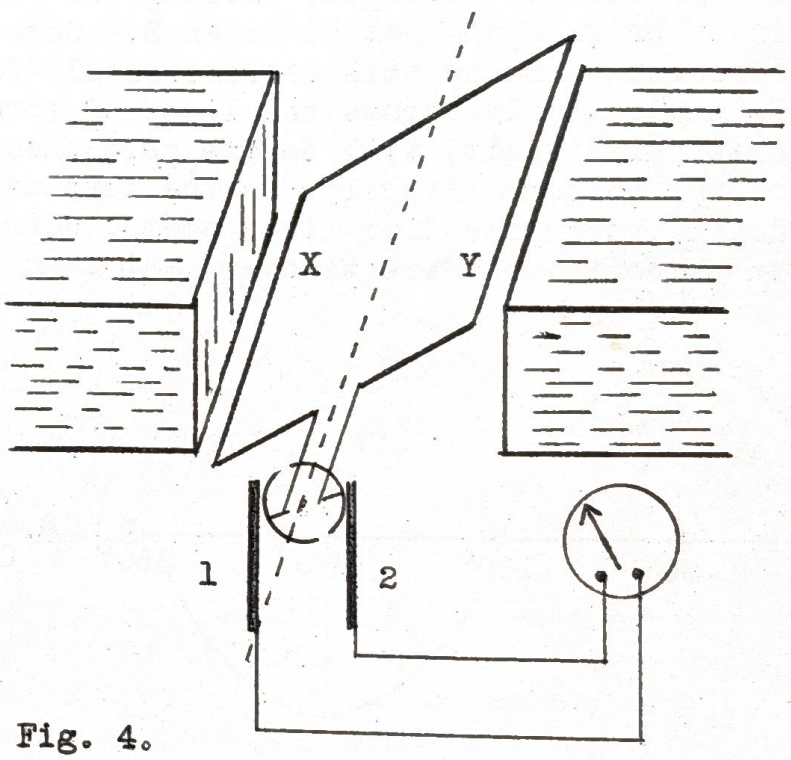


Fig. 4.

the period during which the wires are running parallel to the flux at the top and bottom of the revolution--and that the current in the loop will be reversed each half cycle. Side x moving upward through the flux has a current induced in it in direction A-B, and current in the full loop will flow in direction A-B-C-D. But when section x has passed the top and is commencing to come downward again, current will again be induced into it, thistime in the direction B-A, and the full current in the loop will flow in direction D-C-B-A. As the loop is spun round and round, the direction of current in the loop, and in the external circuit leading out from the slip rings, will be reversed with each half cycle of revolution of the loop. This type of current is known as an alternating current, (a.c.) and is a type extensively used in connection with power transmission. For this reason we may expect to learn much more about it in later lessons.

A.C. & D.C. GENERATORS

In figure three we have illustrated the simplest form in w hich an electric generator may be constructed. The generator consists of a single loop of wire revolved in an electromagnetic field. This loop corresponds to an armature winding of a standard generator, and contact is made with it through slip rings 1 and 2, by means of brushes 3 and 4. As the loop revolves, the side wires cut across the magnetic lines of force existing in the field, and voltages are induced into each side. These voltages, being in series, will act together to cause a current flow in the external circuit leading out from brushes 3 and 4. As previously explained, this external current will reverse its direction once during each half cycle of revolution of the loop. While side x of the loop is moving down across the field of force, and y is moving up, current will flow out at brush 4 and in at brush 3. When the coil is in the vertical position, both x and y will be moving parallel to the lines of force and no e.m.f. will be induced into the loop at that instant, and, consequently, no current will flow. Then, as x comes up and y descends, the e.m.f. will be reversed, causing the current in the external circuit to flow in at brush 4 and out at brush 3. Current in the loop will reach maximum strength when the coil is horizontal, for then both x and y will be cutting perpendicularly across the lines of force. The e.m.f. in the loop, and in the external circuit, will become zero when x reaches the top and y has returned to the bottom. Finally, as the revolution continues and x commences to come down through the flux lines again, current will reverse and once more flow in the original direction.

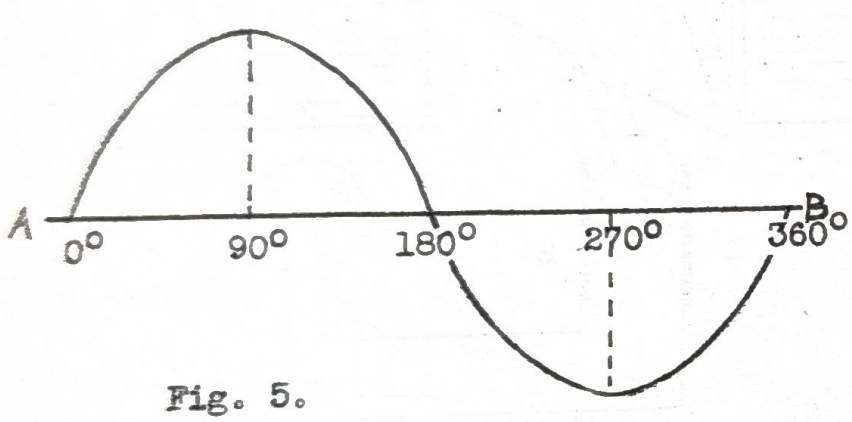


Fig. 5.

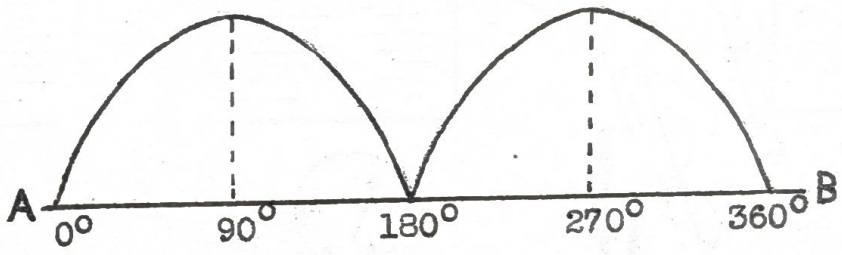


Fig. 6.

Note carefully that in the vertical position of the coil the e.m.f. induced into the loop will be zero, because in that position the wires cut no lines of force. But at the horizontal position, the loop will be cutting the maximum possible number of lines of force, and hence the induced e.m.f. will be at its maximum value.

In figure five the curve of electromotive force for a simple a.c. generator is shown. The curve is a graph, and the strength of current is indicated by the distance the curve extends above or below the zero line A-B. The curve above the line indicates current flowing in one direction, while the section of the curve below the line indicates current flowing in the opposite direction. The zero line A-B is marked off into degrees of one complete revolution of the coil, and in this manner the strength of the current induced into the loop at each part of the revolution can be easily seen and recorded.

Commencing with the loop of figure three in a vertical position, no current will be flowing in the loop. As the loop rotates, current will rise steadily, reaching maximum strength at the 90 degree position. It then falls off until at 180 degrees, or one half turn of the loop, a zero current point is again reached. As the rotation continues our current line falls below zero line, indicating a current flow in the opposite direction. Maximum current in this reverse direction is reached at 270 degrees, and, after this point is passed, current subsides until at 360 degrees a third zero current position is reached.

This type of current is known as an alternating current (a.c.) and goes through one complete cycle in the time of one revolution of the armature of the generator. The common a.c. flowing in power lines has a wave form very similar to that depicted in figure five. Current rise is gradual up to the maximum in the opposite direction, then falls again to zero.

Common a.c. of the power lines usually alternates at a standard frequency of 60 cycles per second, but the frequency in some cases is as low as 25 c.p.s. 60 cycle current, however, is rapidly becoming accepted as the standard.

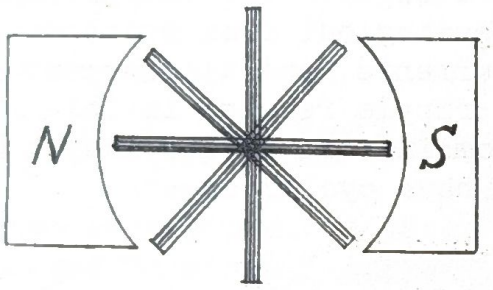


Fig. 7.

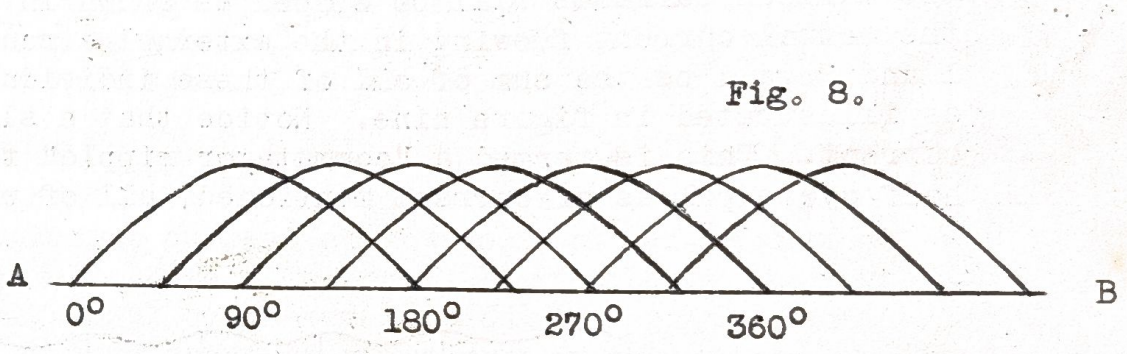


Fig. 8.

DIRECT CURRENT BY ELECTROMAGNETIC INDUCTION

Although a.c. is the common type of power in use today, there are numerous occasions when d.c. (direct current) is the only current suitable to the type of work which must be accomplished. For this reason d.c. generators are a practical necessity and must be considered here. Fundamentally a d.c. generator does not differ greatly from an a.c. generator and actually d.c. may be produced by the simple device illustrated in figure three, providing that it is equipped with a split-segment commutator instead of the slip rings previously considered.

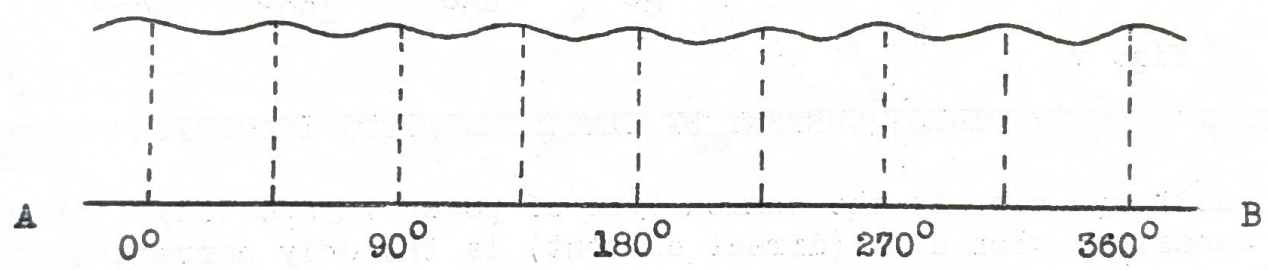
To generate a d.c. voltage by means of the simple generator illustrated in figure three, the loop armature, instead of being joined to the slip rings, may be connected to the two sections of a divided ring, termed a commutator, such as illustrated in figure four. On to this commutator are pressed two flexible springs, or brushes, which are connected to the external circuit. These brushes collect the current generated in the armature winding, and are so placed that they slip from one segment to the other of the commutator just at the instant when the e.m.f. in the loop is reversing. In the diagram the side of the loop descending will always be connected with brush 1, while the ascending side will always be connected with brush 2, and the current in the

external circuit will thus always be from brush 1 to brush 2, irrespective of the position of the armature in the generator.

The current in the external circuit leading out from the two brushes will correspond to the curve outlined in figure six. Each section of the curve represents half the period of revolution of the armature. This current though always flowing in the same direction, will be a fluctuating current, rising from zero to maximum and falling again to zero once during each half cycle of revolution.

This cyclic fluctuation in the voltage of a d.c. generator has been largely eliminated by employing a type of armature in which a great many different loops, or coils, are contained, each situated so as to form a different angle to the original single loop. This type of armature is illustrated in diagram form in figure seven. Note that the various armature loops or coils, all rotate on the same shaft, and that they cross over one another in such a manner as to form equal angles between themselves. Each individual loop will thus generate a voltage rising to maximum at a different point in the revolution of the armature. These armature coils lead out to separate commutator segments. Although the voltage generated in each individual armature coil will remain substantially equal to that illustrated in figure six, the various currents will be spaced as shown in figure eight. For this reason the actual current flowing in the external circuit leading out from brushes 1 and 2 will be the sum of all of these individual currents, and will appear as illustrated in figure nine. Notice that a slight ripple remains in this current. This is termed a "commutator ripple" the combination of the many half-cycle pulses of current mentioned, all of which have cyclic crests.

Fig. 9.



By increasing the number of coils in the armature, the intensity of the commutator ripple may be greatly reduced, but it can never be eliminated entirely excepting where filtering is resorted to.

FIELD MAGNETS

In the simple generators illustrated in figures three and four, the loop armature is revolved in the field existing between two permanent magnets. But this principle is scarcely suitable for use in actual practice. The field magnets of the ordinary generator are almost always electromagnets consisting of many turns of wire wound in channels in the generator frame, or around a special field magnet core. These magnets, in d.c. generators, receive their exciting current from the armature--that is, the current generated in the armature of the dynamo flows through the field windings and energizes the field magnets, thus making the generator self-contained and independent of

externally excited electromagnets or permanent magnets. The field coils may be connected in series with the armature, or they may be connected in shunt across the armature windings. In either case only a small portion of the electric energy generated in the dynamo will be spent to maintain the magnetic field.

A.C. cannot be used to excite the field windings of a generator, and therefore the field coils of a.c. generators must either be fed with d.c. from some external source, or the generator must be equipped with a commutator for collecting d.c. for field exciting purposes (in addition to the slip rings for collecting a.c.), or it may be equipped with a small auxiliary d.c. generator, driven from the same source of power, which can be utilized to supply the field exciting current. All of these systems are in common use.

A.C. TRANSMISSION

On first thought it would seem that direct current is the ideal type of power for transmission purposes. But this is not actually the case. The difficulty in using d.c. power is that it cannot easily be converted from one voltage to another, and for this reason it is impossible to keep a long feeder line operating at constant voltage from one end to the other. Resistance losses occur in every transmission line, and in a very long line these may become so great as to render the lighting of globes at the far end very inefficient.

A.C. voltage, on the other hand, can be boosted over and over again as often as desired. A large alternating current at low voltage can be easily changed to a small current at high voltage. The small high-voltage current can be carried by a comparatively small conductor to a distant point where it can be transformed into a very large current at a low enough voltage to be safely used for light or power.

The advantage of this plan arises from the fact that resistance opposes current strength, and is not concerned with actual power. Power is the multiple of current and voltage and may be the same for a low current at high voltage, as for a strong current at low voltage. But as resistance acts to retard current without consideration of either the applied voltage, or the actual power being transmitted, resistance losses will be much greater in the second instance than in the former.

TRANSFORMERS

Alternating currents may be easily changed from low voltage to high voltages, or vica versa, by means of transformers, the elementary principles of which were considered in lesson six when we discussed magnetic circuits.

A transformer consists of two coils placed over a common iron core. The core is usually made of a pile of thin sheet-iron plates grouped into the form of a thick block having two rectangular holes through which the coils are wound. When an alternating current is set up in one coil, it magnetizes the iron core, setting up lines of force in the core, and these pass through the second coil. But the lines of force are not stationary as are the lines of force surrounding a bar magnet or a coil energized by d.c. The lines of

force set up by a.c. rise from zero to a full value, fall to zero, then rise to maximum in the opposite direc tion (due to the alternation of direction of the flow of current in the winding), fall again to zero, and so on. Each time the flux strength rises or falls, the lines of force induce voltage into the windings of the second coil. The passage of power through from one winding of the transformer to the other is thus possible and in carefully designed transformers is quite efficient.

The voltages in the primary and secondary circuits of a transformer will be in the ratio of the number of turns in the primary and secondary windings. If the primary consists of 1,000 turns of wire, and the secondary 500, the voltage developed across the secondary will be only one-half that impressed across the primary. Current strength, however, will be doubled indicating that little or no power has been lost.

A.C. RADIOS

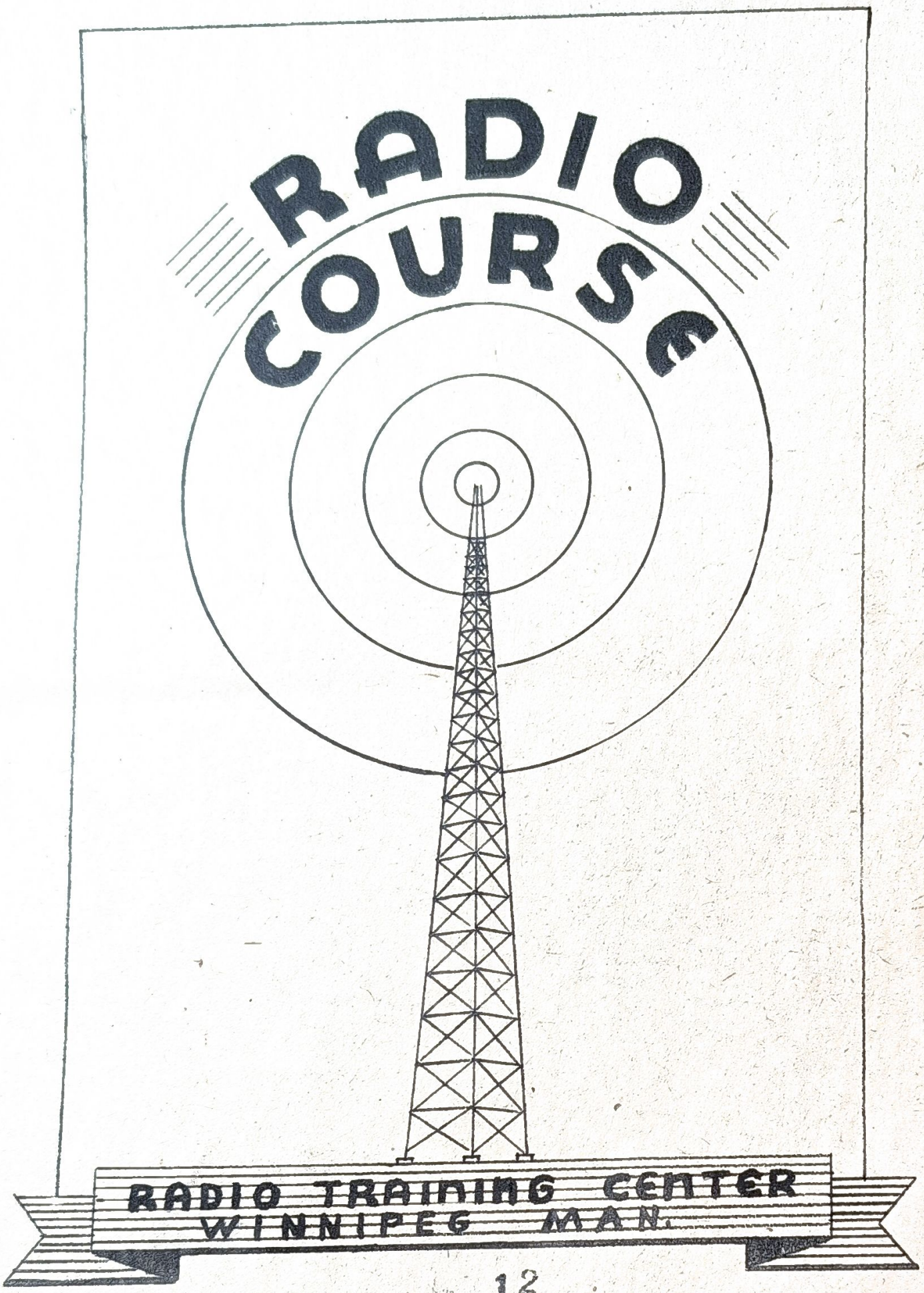
For many years after the first sets appeared upon the market, radio receivers everywhere were operated from battery power. This was the case even in homes wired for electricity. A.C. sets were not available, and it is only within comparatively recent years that practical a.c. radios have been built.

The problem in using a.c. to power a radio receiver, is the fact that the alternations of current occur at an audio frequency--that is, at a frequency that can be heard. Standard a.c. frequencies are 60 and 25 c.p.s. If an a.c. radio is not designed in a very careful and special manner, it is impossible to keep this frequency from mingling with the sounds produced by the speaker. A.c. manifests itself in the speaker as a very annoying bass hum known generally as "a.c. hum", and its elimination is often a serious problem even in the case of modern radios.

The operation of a radio receiver from a.c. socket power is made possible through a system of converting a.c. to d.c. known as "rectification", by means of which d.c. plate (or "B") voltages may be obtained directly from an a.c. source. Special heater type tubes also are employed. The cathodes of these tubes have a high "thermal lag" which prevents the variations of current strength from affecting the amplification power of the tube, and so eliminates another source of a.c. hum.

TEST QUESTIONS

1. In Figure 2, when the wire is held stationary in the magnetic field, no current will be induced into it. Why is this?
2. Does the speed at which a wire is forced through a magnetic field affect the strength of current induced into the wire?
3. In connection with Figure 3, why does the current in the loop reverse with each half cycle of revolution?
4. What is an alternating current?
5. Outline briefly how a d.c. generator differs from an a.c. generator.
6. Is it possible to satisfactorily energize the field magnets of a generator with a.c. current? (speaker of a radio set?
7. What term is commonly used in describing the sound produced by a.c. in the
8. What are the two most common standard frequencies of a.c. power?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LESSON TWELVE

ELECTRICAL MEASUREMENTS

In making practical use of electricity, certain units of measurement are necessary. We are all familiar with the units of long measure -- the foot, the yard and the mile -- with the gallon in liquid measure, and with the point in weight. The units of electrical measurement are just as real as any of these, though they cannot be illustrated so readily. Some of the units of electrical measurement have already been mentioned, for instance, the volt, (the unit of electrical pressure) the ampere (the unit of electrical flow), and the ohm (the resistance unit).

Thus far in our study, whenever we have wished to ascertain the voltage, or amperage, or resistance of a circuit, we have done so by simple calculation, but this is not the most practical method for use on actual electrical circuits. In practice we must resort to the use of meters and other measuring devices.

Practically all electrical measurements are made with two meters -- the voltmeter and the ammeter, and the purpose of these two meters must be thoroughly understood. New students of electricity are often in doubt as to the difference in purpose, and in design, of these two instruments. It is not sufficient to say the voltmeter is intended to measure voltage, and the ammeter amperage, for the meaning of these terms too is often in doubt. In the following description we will try to make the matter just as clear as possible.

VOLTAGE AND AMPERAGE

In figure one, when switch S is closed, current will flow from battery B, through switch S, load L, and back to battery B. Voltmeter V is connected across the voltage source and records the full voltage of the battery, whether or not current is flowing through the circuit including load L. Opening or closing switch S will not alter the voltage reading of voltmeter V.

Now turning to figure two: Here ammeter A is placed in series with load L. After closing switch S, current will begin to flow from battery B through ammeter A, through load L and back to battery B. As the ammeter is in series with load L, the full current flowing through the load will also flow through the ammeter and will be measured by it. In figure two, if switch S is opened, what will be the result? The pointer of the ammeter will drop to zero, indicating that current is no longer flowing through load L, but the voltage read by voltmeter V will remain constant. If the load is made variable, as illustrated in figure three, some very interesting observations may be made. Commencing with load L adjusted to the position of maximum resistance, current will be very low, but voltmeter V will continue to register the full voltage of the battery. Sliding the contact of variable resistor L, so that the resistance will become gradually less and less, current through ammeter A will be found to rise with each reduction of the resistanceof the load. Why this action occurs should be easy to see. Current flows from battery B through the series circuit consistain g of ammeter A and resistor L. Thr current flow

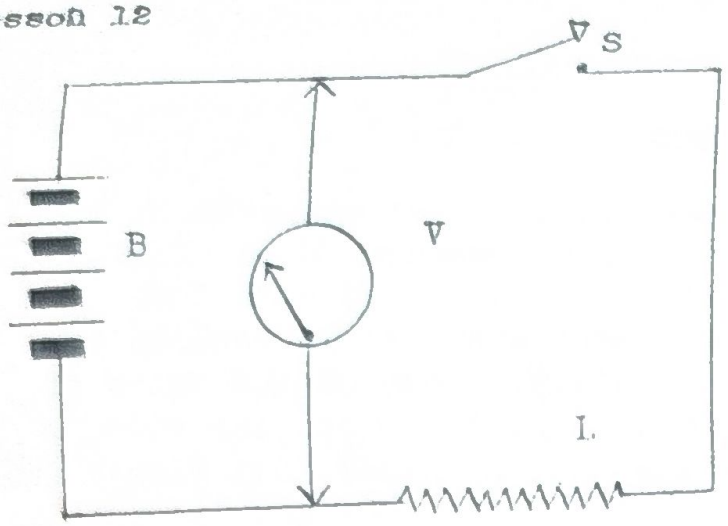


Fig. 1.

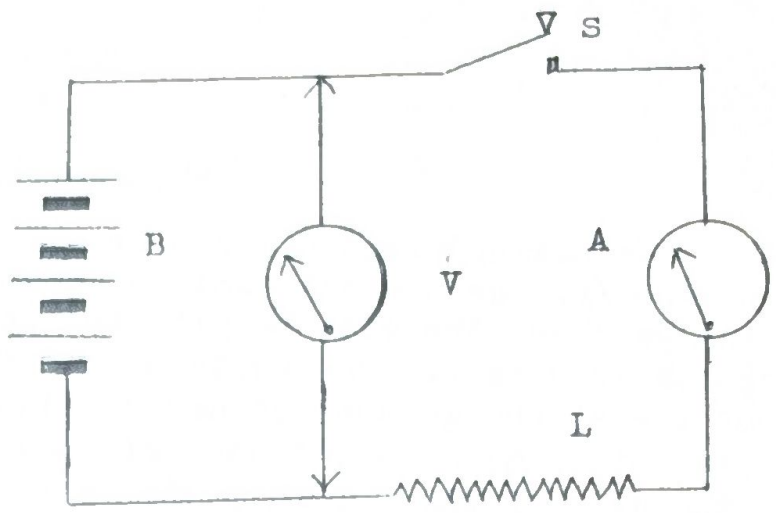


Fig. 2.

will be governed by the resistance of the circuit .. i.e., the combined resistance of load L and ammeter A. The resistance of an ammeter, however, is very low, and may be considered for the moment as being negligible. Thus the resistance of load L will govern the amount of current flowing in the circuit. Variations in current flow will be recorded by the ammeter. The voltage of the battery will remain constant, and will be steadily recorded by voltmeter V.

The student may be wondering why, because the voltmeter is connected across the battery terminals, a large current does not flow directly through it. This question will be answered in detail before we complete the lesson. For the moment we ask the student to spend a little time in thinking it over. There is a logical reason why a heavy current does not flow through the voltmeter, which the student will very likely be able to discover for himself.

In figure four the voltage applied to a circuit, and the current flowing through that circuit, are both controlled by variable resistors. When switch S is closed, current flows from battery B, through resistor 3-4 and back to the battery. The current through resistor 3-4 divides at point 5, and a portion flows out through ammeter A, load L, and back to battery B along conducting wire 6-4-1. Voltmeter V1 records the constant voltage of the battery while voltmeter V2 records the variable voltage applied to load L (through ammeter A). If sliding contact 5 is moved up and down between points 3 and 4, the voltage recorded by meter V2 will rise and fall. When the voltage across points 5 and 4 (recorded by V2) is increased, a heavier current will be found to flow through

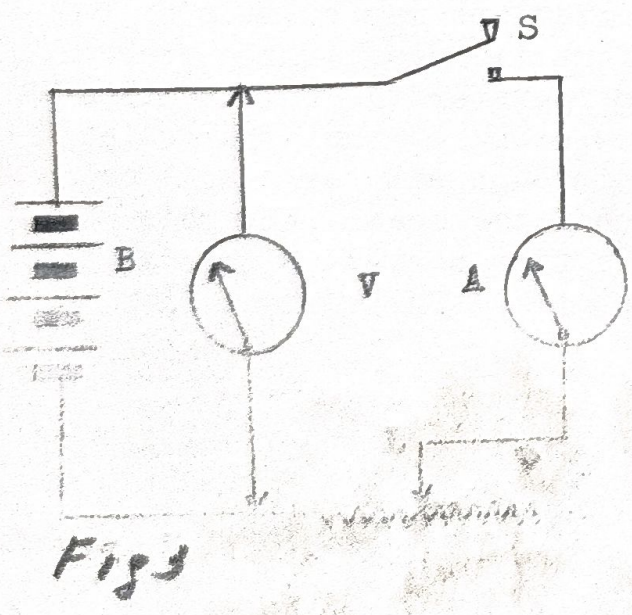


Fig3

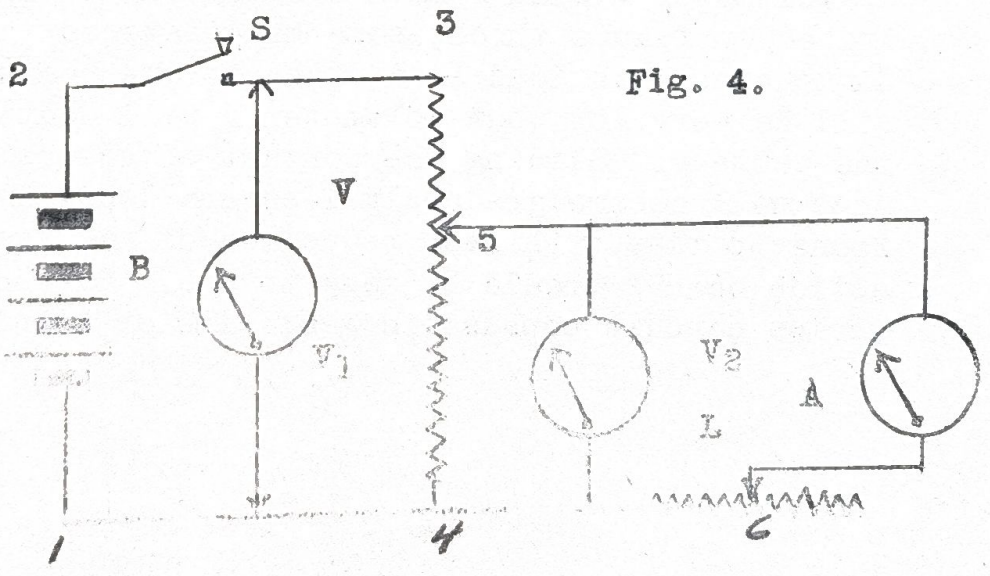


Fig. 4.

load L and ammeter. This is not surprising, for we have learned that current flow in a circuit is controlled by two things, namely, the voltage applied to the circuit, and the resistance of the circuit. The voltage applied to the circuit commencing at point 5, including ammeter A, load L, and returning to point 4, is clearly equal to the voltage drop set up across resistor section 5-4. This voltage is measured by voltmeter V2.

As the position of moving contact 5 is varied, so as to increase the voltage applied to load L, the pointer of ammeter A will advance, indicating that a larger current is flowing through the load, but, if now the resistance of variable resistor L is increased as the voltage recorded by voltmeter V2 increases, and in direct proportion to this voltage increase, the current recorded by ammeter A (as flowing through resistor L) will be found to remain constant. Understand why this should be, for the situation is quite simple. The voltage applied to the circuit is increased by adjustment of the sliding contact 5, of resistor 3-4, and at the same time the value of the load resistance L is increased. We will assume that the voltage increase is proportionate to the increase in load. If this is so, the current through the ammeter and load will remain constant, which is exactly the result we should have expected.

The nature of the measurements made with voltmeters and ammeters should now be fairly clear in the students mind. An ammeter is inserted in series with a load, and records the current passing through the load. It does not and cannot, record the voltage applied to the load. This is made very clear in the description of figure four. By increasing the voltage and the load in unison, the current through the load was held constant. The reading of ammeter A did not vary because current through the load did not change. Clearly the ammeter does not record the voltage applied to a circuit. The voltage applied to this particular circuit was increased, but yet because of an adjustment made to load L, the ammeter reading was held constant.

Because an ammeter must be connected in series with the load, it must have a very low internal resistance. On the other hand, a voltmeter, which is always connected across the load, or across the source of e.m.f., must have high resistance. A voltmeter is connected in parallel with the object across which the voltage is to be measured, while the ammeter is connected in series with the object through which the current flow is to be ascertained. In figure four, voltmeter V1 is in parallel with voltage divider resistor 3 4, while voltmeter V2 is in parallel with the circuit including ammeter A and load resistor L.

Because a voltmeter is always connected in parallel with the load or other object across which the voltage is to be read, it forms a shunt to the load a parallel path through which current may flow. Because of this fact, a voltmeter must have high resistance. As a voltmeter is often connected across

very high voltage sources, it would be subjected to heavy current flow if it were not constructed in such a manner that it has high internal resistance, capable of reducing current through it to a minimum.

D. C. AMMETER

The operating principles of both the voltmeter and the ammeter are based upon magnetic attraction. In figure five, the internal construction of an ammeter is outlined. A rectangular coil of wire is mounted so as to surround a stationary iron core situated in the magnetic field produced by a permanent magnet. The armature, as the moving coil is termed, is mounted on a shaft which is free to rotate in pivots situated at top and bottom of the iron core.

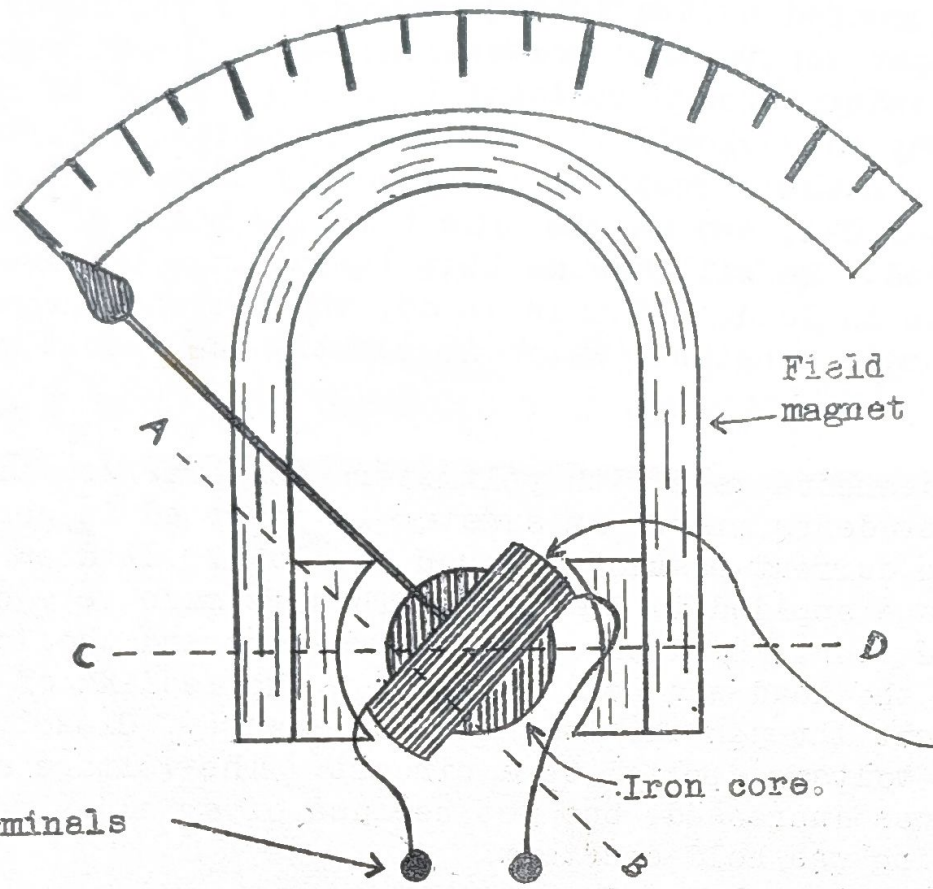


Fig. 5.

Basic construction of ammeter and voltmeter.

A pointer attached to the moving coil slides over a graduated scale when the coil is activated by an electric current. When no current is flowing in the armature coil, the pointer is held at zero position on the scale by means of a coil hair-spring, not illustrated.

When an ammeter is connected in series with a current-carrying circuit, current flows in the armature coil and a magnetic field is set up surrounding this coil. Notice the slanting position in which the armature coil rests when in the zero scale position . The field surrounding this coil will be at right angles to the coil and will extend through it in lines parallel to dotted line a-b figure six, but the field existing between the poles of the permanent magnet will be parallel to line c-d. Now when two magnetic fields come into

close contact with one another, there is a tendency for the fields to line up with each other so that all of the lines of force may run in the same direction. Thus the armature coil in our illustration will be forced around until line a-b coincides with line c-d, provided that the current strength in the coil is sufficient. The movement of the armature coil is opposed by the force of the spring with which the pointer is held to the zero scale position, and thus a considerable current may be required to pull the armature all of the way around. Lesser currents will pull it through fractions of the full distance, and various strengths of current will cause the pointer to move over the scale to distances proportionate to the momentary strength. If the pointer is moving acress a scale graduated into a hundred segments, then a certain current in the armature coil will cause the pointer to reach 100 on the scale, half of this current will cause the pointer to reach 60, a quarter of the current will cause it to reach 25. and so on.

The student will probably have decided in his own mind that the armature coil of the ammeter, being of rather fine wire, will hardly be able to carry the full current of any circuit the current of which it will be called upon to measure. Acturally this is a problem with which the designers of ammeters are always confronted. The usual procedure is to start with a "foundation meter" and an ammeter designed and graduated to read in thousandths parts of an ampere. Such a meter is referred to as a milliameter. The) 1 milliameter is an instrument commonly used for this purpose. It is an ammeter designed to carry a maximum current of one one thousandths of an ampere, and which will, of course, give full pointer deflection when a current of this strength is flowing through its windings. The resistance of the instrument is next carefully calculated. This resistance must be kept very low. A resistance of less than 100 ohms is common among better built milliammeters. If the instrument is intended to read 0-10 amperes, the moving coil, which has a resistance of 100 ohms, will be shunted by a resistor carefully designed to have a resistance of exactly one one-hundredths ohm. The reason for arriving at this exact value should be clear to the student. The meter now presents parallel paths to the flow of current. Although the ammeter, as a unit, is always connected in series with the load and the source of e.m.f., the current passing through the ammeter will divide, part passing through the armature coil, and part through the shunt. In our example the armature winding will carry only one ten-thousandth part of the full current flowing through the load, while the shunt carries the remainder of the current. If the resistance of the moving coil is exactly 10,000 times the resistance of the shunt, the reading of the pointer on the scale will be an accurate indication of the full current flow, but obviously everything depends upon accurate calculation of the values of these two resistances. If the meter is to be used with the same shunt all of the time -- that is, if the meter is intended always to be used to read currents of 0-10 amperes -- then the scale may be graduated and printed to read directly in amperes. The full pointer scale then would indicate 10 amperes, half scale swing, 5 amperes, one-fifth scale, two amperes,

and so on. This, however, is not the method usually utilized with sensitive test meters. The owners of sensitive test meters often wish to use these meters in many different positions, and to read many different values of current with the same meter. The student may have reasoned that by changing the value of the shunt employed with the foundation meter, various current readings may be made. This is quite true. With the single foundation meter already mentioned, which had a resistance of 100 ohms, by utilizing interchangeable shunt resistors of 1/100th, 1 and 10 ohms, readings of 0-10 amperes, 0-1 amperes, 0-100 milliamperes and 0-10 milliamperes may be had. In addition to these readings, the basic reading of the meter without shunt (0-1 mills,) may also be had.

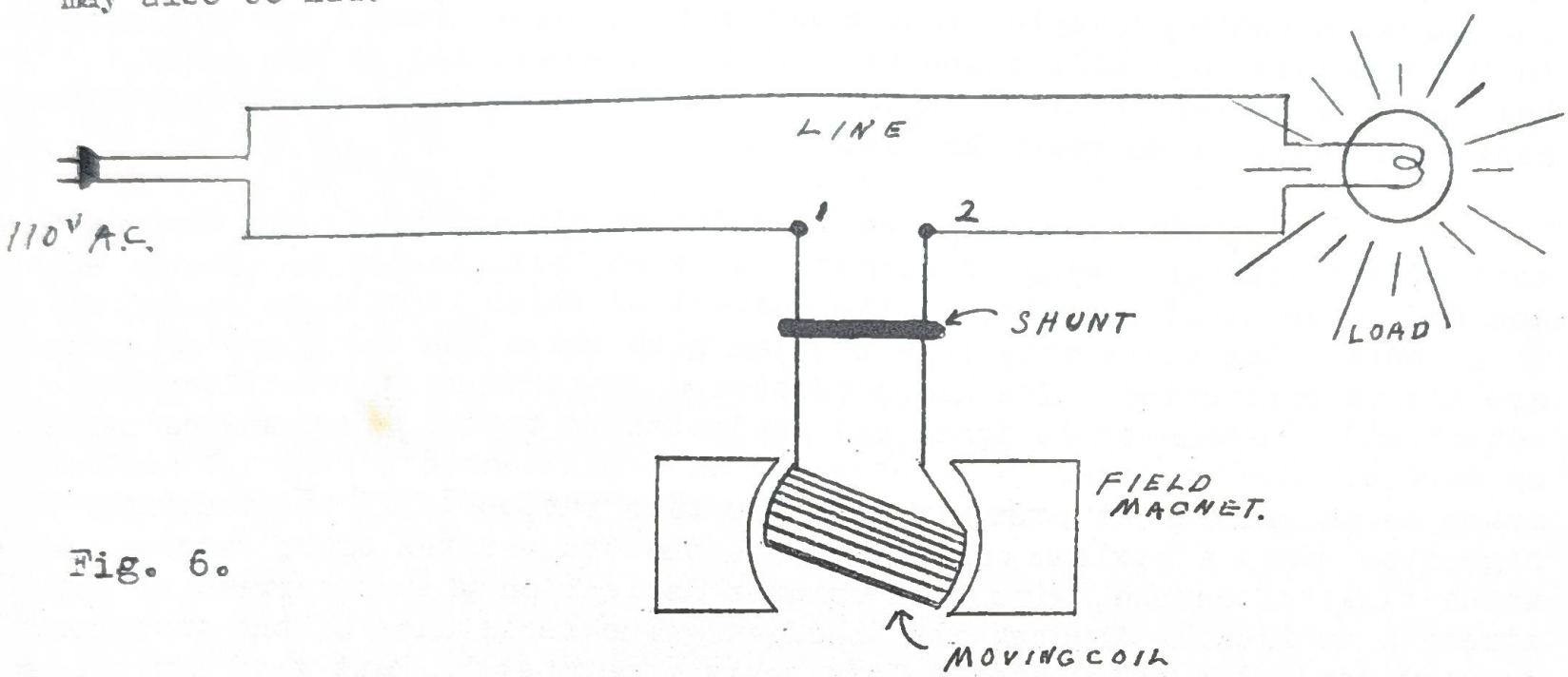


Fig. 6.

How a milliammeter will appear when connected into a simple circuit, is illustrated in figure six. Here a light globe is connected to a source of 110 volt socket power. The ammeter is placed in series with the circuit in order that the current flowing through the globe may be measured. Notice carefully that all of the current of this circuit must flow through the meter assembly, either passing directly through the moving coil, or through the shunt. The section of the circuit enclosed in dotted lines, and referred to here as the meter assembly, is usually enclosed in a single case and is considered simply as an ammeter, a self contained unit through which the current of the circuit must pass. But we, as electricians must never forget that, in the majority of cases, an ammeter actually contains within itself a parallel network consisting of a shunt through which the main portion of the current will flow, and the moving coil which activates the meter pointer, but through which only a fraction of the total current of the circuit really flows.

In radio test equipment the principle of extending the range of simple foundation meters is extensively used, and the same foundation meter may be

used both as a multi-range ammeter and as a multirange voltmeter. Such a meter is termed a "multimeter" and is a very versatile instrument indeed.

D. C. VOLTMETER

A voltmeter does not differ from an ammeter in bare structural details. In it, too, a small moving coil is activated by a flow of current, and so is caused to rotate in a surrounding magnetic field. A moving coil and field magnet assembly, such as might be used in either a voltmeter or an ammeter, is illustrated in figure five. Notice that for its operation a voltmeter requires a flow of current through its armature coil. As this is exactly the same action that we mentioned taking place in an ammeter, we see that the principle difference between an ammeter and a voltmeter is not in the basic meter itself, and must therefore center in the manner in which the meters are connected into their respective circuits.

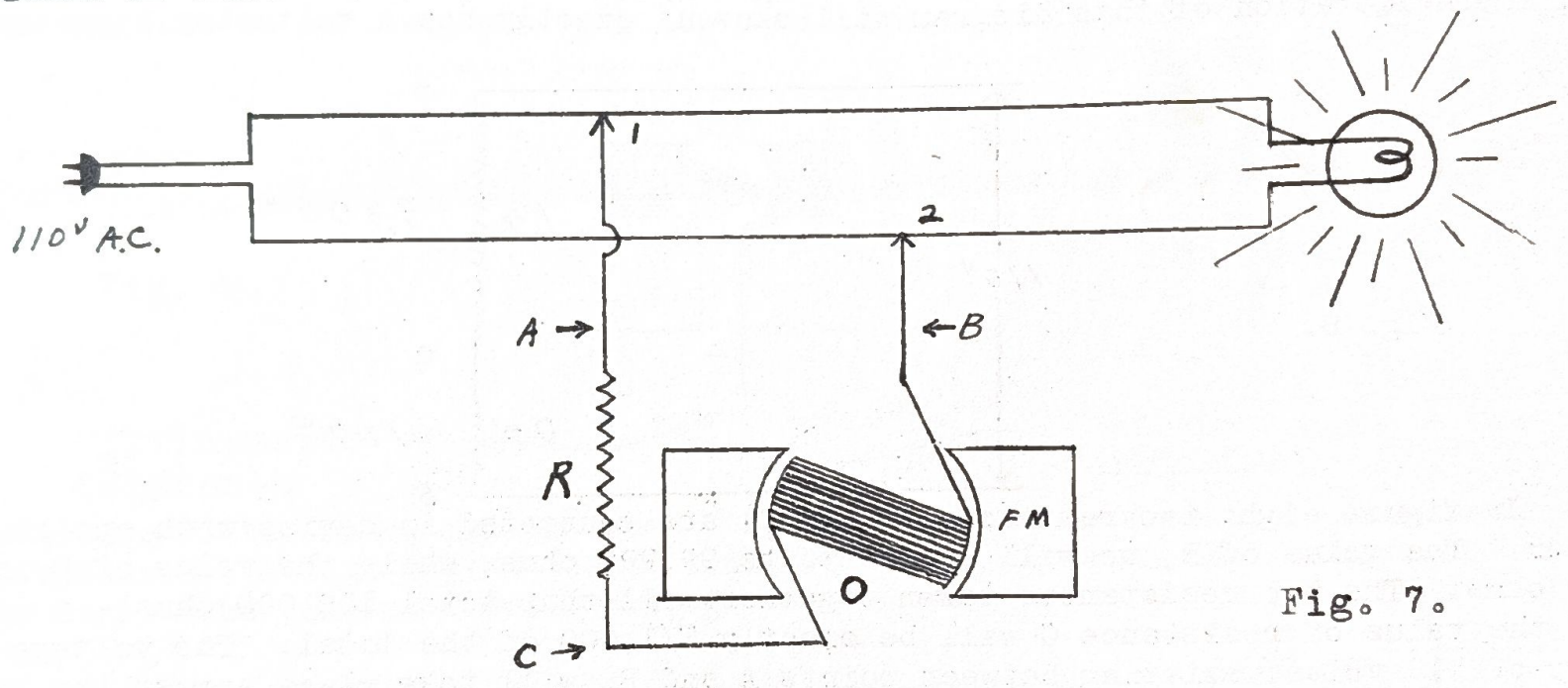


Fig. 7.

If we were to take any D. C. milliammeter and add a series resistance to limit the amount of current which may flow through the meter, we would have a d.c. voltmeter.

The external resistance used with a voltmeter is known as a multiplier and must be of resistance carefully calculated to work with the resistance of the meter unit itself. The voltmeter with its series resistor, which is an integral part of the voltmeter and seldom considered separately, is connected directly across high voltage sources. A current flows through the limiting resistor and the coil winding of the meter. If the meter unit is very sensitive, being perhaps an 0-1 milliammeter with an internal resistance of 100 ohms, then by using an external multiplier resistor of 100,000 ohms, only one-thousandth part of the full voltage drop will take place across the moving coil of the meter. If the entire assembly (foundation meter and series resistor) is connected across a voltage source of 100 volts, the voltage drop across the voltmeter will be 100 volts, and across the

moving coil, one-tenth of a volt. This might appear at first sight to be a very low voltage drop with which to activate the armature coil of the meter, but, due to the fact that the foundation meter is a 100 ohm, 1-0 milliammeter, it will be seen that one-tenth of a volt across the armature coil will be sufficient to cause full scale deflection.

How a voltmeter will appear when measuring the voltage of a circuit is illustrated in figure seven. Here the meter assembly, consisting of armature coil A and series current limiting resistor R, is connected directly across the line carrying current to the bulb. One terminal of the meter assembly is connected to one wire of the line, while the other terminal is connected to the other wire. The full voltage of the line will thus be impressed across the meter assembly and consequently will exist between A and B in the meter. The full voltage of the line will probably be 110, and this means that a voltage drop of 110 volts will exist between points A and B in the meter circuit. For convenience this voltage drop may be so considered as two lesser voltage drops, one existing between A and C, across the series resistor, and one existing between C and B, or across the moving coil. These two resistances are redrawn schematically in figure eight, and a consideration of this diagram will show us exactly how a voltmeter operates.

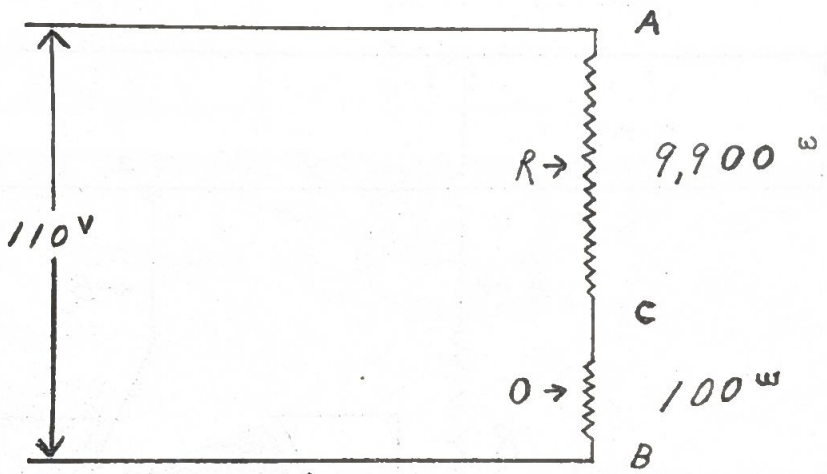


Fig. 8.

In figure eight two resistors (R and 0) are connected in series with one another. The value of R, we will assume to be 99,900 ohms, while the value of 0 is 100 ohms. The two resistances taken together will thus total 100,000 ohms, and the value of resistance C will be exactly 1/1,000 of the total. The voltage drop of 110 volts, existing between points A and B, will take place across the two resistors in this proportion: 999/1,000 of the total will appear across resistor R (between A and C) and 1/1,000 of the total across resistor 0 (between C and B). The voltage drop across resistor 0, being only 1/1,000 of 110, will thus be only .11 volt.

It will be seen from this that even though large voltages are applied to the voltmeter assembly, because of the use of a high value series resistor, the actual voltage which is impressed across the armature coil of the device will be quite low, and consequently will not cause a very heavy current to flow through its windings. If our foundation meter is an 0-1 milliammeter, having an internal resistance of 100 ohms, the .1 volt (1/10 volt) impressed across the armature coil

will cause only one milliampere of current to flow through the armature coil, but this small current will be sufficient to cause full scale deflection of the meter needle,

In voltmeter design the chief problem is to construct a foundation meter sufficiently sensitive that the actual current through the assembly of meter and series resistor may be held to a very low value. The current through a voltmeter must be kept low in order that this current will not react to upset the voltages across resistors carrying slight currents. This subject will be gone into more thoroughly in later lessons. For the moment it will be sufficient to remember that, as a general rule, the higher the resistance and the lower the current thr- ough a voltmeter, the more accurate and reliable it will be.

VOLTMETERS AND AMMETERS COMPARED

A single sensitive milliammeter may be used both as an ammeter and as a volt- meter. When used as an ammeter it is connected in series with the load, and the moving coil is shunted by a very low resistance so as to reduce the effective re-

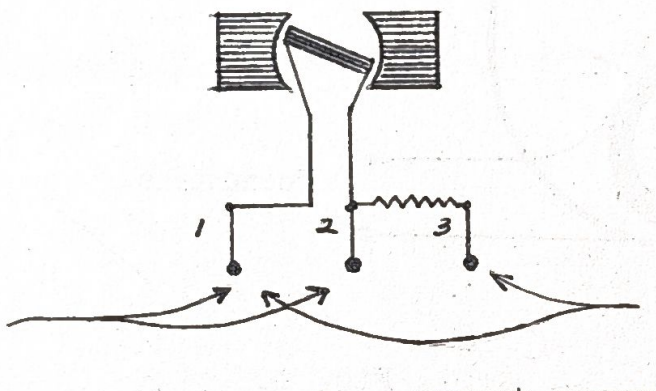


Fig. 9.

sistance of the meter and increase its current carrying capacity. When used as a voltmeter, a high resistance is connected in series with the moving coil so as to limit the current flowing through the device.

A single meter may be connected into a special circuit such as is illustrated in figure nine, and used interchangeably as a voltmeter or milliammeter. In figure nine, the moving coil of the foundation meter is connected to terminals 1 and 2, and the lead connected to terminal 2 is connected through resistor R to terminal 3. In order to use the meter as a milliammeter, it is only necessary to connect wires directly to terminals 1 and 2. When the meter is to be used as a voltmeter, the wires will be connected to terminals 1 and 3, in this manner including resistor R in series with the meter. The range of the foundation meter may be extended as a milliammeter (or ammeter) by the addition of suitable shunts which may be placed between terminals 1 and 2. The range of the meter, when used as a voltmeter, may be altered by changing the value of resistor R.

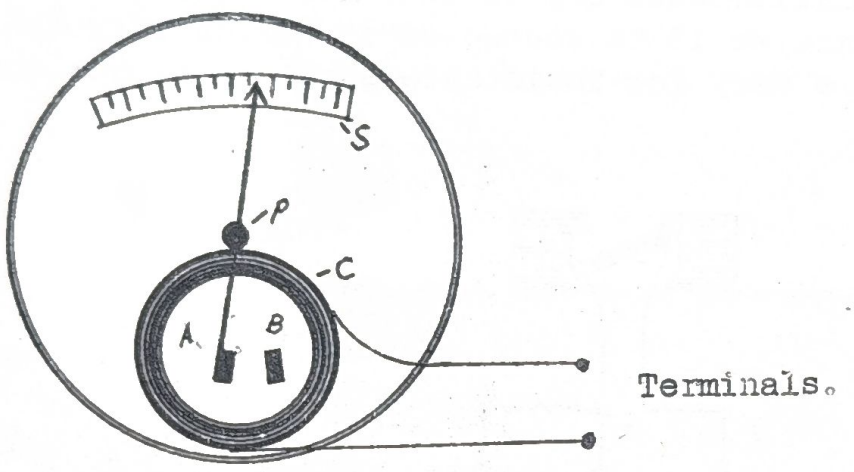
A meter of the type described, including shunts and series resistors arranged in such a manner that they may be switched in or out of the circuit at will by simply turning a dial, is available commercially. It is known as a "multimeter"

and is a very useful type of test meter for the radio service man to have.

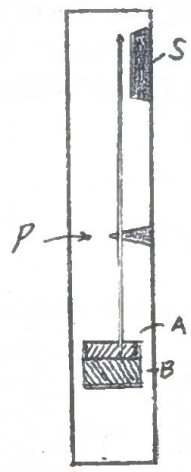
A. C. METERS

The meters previously described are intended to operate on direct current only. Yet in radio and electrical work the currents and voltages which must be measured are very often of alternating polarity. The meter illustrated in figure five could not be used in the measurement of A.C. current. The pointer of this type of meter will read "up scale" only if current is passing through it in the proper direction. If an A.C. current were measured by this meter, the pointer would swing rapidly up and down, or stand perfectly still if the frequency of alternation was too great. This difficulty encountered in reading A.C. voltages and currents has been overcome by making use of the principle that

A. C. Meter.



Top View.



Side View.

Fig. 10.

like magnetic poles repel each other. A common type of A.C. meter is illustrated in figure ten. It consists of a stationary coil C, inside of which, acting as a core, are two flat bars of soft iron, A and B. When current is passing through the coil, the two bars become magnetized, each in the same direction, and thus tend to repel each other. One bar is pivoted and has a pointer attached. This bar pivots away from the other and its movement is follow ed by the pointer over a scale. The amount of deflection of the pointer will be proportionate to the strength of current in the coil.

Several other types of A.C. meters have been developed, and some of these will be described in a later lesson of the course. Most of them, however, operate upon the basic principle outlined here, though the actual mechanism may differ widely from the type illustrated in figure ten.

(1) In figure four, will the voltage reading of voltmeter V1 be increased as sliding contact 5 is moved from point 3 towards point 4?

(2) Will altering the value of resistor L, in figure 3, affect the voltage reading of voltmeter V?

(3) In figure four, which variable resistor (3-4 or L) would you adjust to change the reading of voltmeter V2?

(4) Why is the moving coil of an ammeter usually shunted by a low value resistor?

(5) Why is a current limiting resistor used in series with the moving coil in a voltmeter?

(6) Can the ordinary ammeter, as illustrated in figure five, be utilized to measure a.c. currents? Explain your answer briefly.